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ABSTRACT

Proper installation, inspection, operation, maintenance, repair and management of small water systems have a significant impact on the operation and maintenance cost and effectiveness of the systems. The objective of this manual is to provide small water system operators with the knowledge and skills required to operate and maintain these systems effectively. This manual contains information on: (1) what small water system operators do; (2) sources and uses of water; (3) how to operate and maintain wells and pumps; (4) the operation and maintenance of small water treatment plants; (5) the disinfection of new and repaired facilities as well as water delivered to consumers; (6) techniques for recognizing hazards and developing safe procedures and safety programs; (7) laboratory procedures for analyzing samples of water; and (8) procedures to develop a reasonable rate structure. The document was developed to serve as a home-study or self-paced instructional course. The appendices include a trial final examination (with answers), tips on solving small water system arithmetic problems, water abbreviations, a glossary of water words, and a subject index. (TW)

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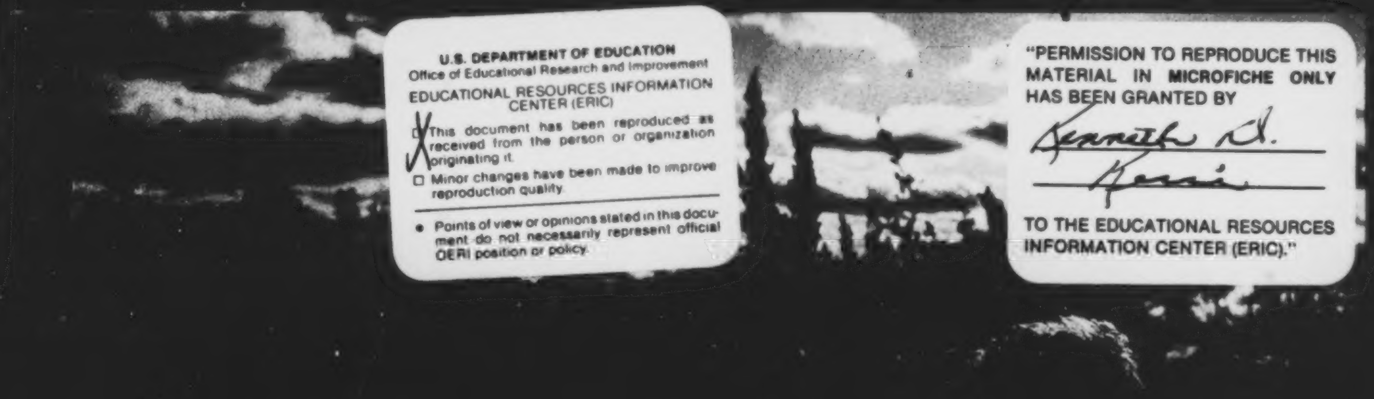

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This training manual has been reviewed by the Office of Drinking Water, U.S. Environmental Protection Agency and the California Department of Health Services. Both agencies have approved this manual for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency nor the California Department of Health Services. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Environmental Protection Agency; California Department of Health Services; California State University, Sacramento; National Environmental Training Association; authors of the chapters or project reviewers, consultants, and directors.

SMALL WATER SYSTEM OPERATION AND MAINTENANCE

Second Edition

A Field Study Training Program

prepared by

California State University, Sacramento
School of Engineering
Applied Research and Design Center

in cooperation with the
National Environmental Training Association

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Kenneth D. Kerri, Project Director

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for the

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Office of Drinking Water
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1987

OPERATOR TRAINING MANUALS IN THIS SERIES are available from Ken Kerri, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819-2694, phone (916) 278-6142:

1. *SMALL WATER SYSTEM OPERATION AND MAINTENANCE,*
2. *WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE,*
3. *WATER TREATMENT PLANT OPERATION,* 2 Volumes,
4. *OPERATION OF WASTEWATER TREATMENT PLANTS,* 4 Volumes, and
5. *OPERATION AND MAINTENANCE OF WASTEWATER COLLECTION SYSTEMS,* 2 Volumes.

NOTICE

This manual is revised and updated before each printing based on comments from persons using this manual.

FIRST EDITION, WATER SUPPLY SYSTEM OPERATION

First Printing, 1983 7,000

SECOND EDITION, SMALL WATER SYSTEM O & M

First Printing, 1987 7,000

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PREFACE TO THE FIRST EDITION

The purposes of this water supply system field study training program are to:

1. Develop new qualified water supply system operators,
2. Expand the abilities of existing operators, permitting better service to both their employers and the public, and
3. Prepare operators for civil service and *CERTIFICATION EXAMINATIONS.*[1]

To provide you with the knowledge and skills needed to operate and maintain water supply systems as efficiently and effectively as possible, experienced water supply system operators prepared the material in each chapter of this manual.

Water supply systems vary from city to city and from region to region. The material contained in this program is presented to provide you with an understanding of the basic operation and maintenance aspects of your system and with information to help you analyze and solve operation and maintenance problems. This information will help you operate and maintain your system in a safe and efficient manner.

Water supply operation and maintenance is a rapidly advancing field. To keep pace with scientific and technological advances, the material in this manual must be periodically revised and updated. *THIS MEANS THAT YOU, THE OPERATOR, MUST RECOGNIZE THE NEED TO BE AWARE OF NEW ADVANCES AND THE NEED FOR CONTINUOUS TRAINING BEYOND THIS PROGRAM.*

BASIC TRAINING • ADVANCED TRAINING • CERTIFICATION EXAMINATION

The Project Director is indebted to the many operators and other persons who contributed to this manual. Every effort was made to acknowledge material from the many excellent references in the water supply field. Reviewers Leonard Ainsworth, Jack Rossum, and Joe Monscvitz deserve special recognition for their extremely thorough review and helpful suggestions. John Trax, Chet Pauls, and Ken Hay, Office of Drinking Water, U.S. Environmental Protection Agency, and John Gaston, Bill MacPherson, Bert Ellsworth, Clarence Young, Ted Bakker, and Beverlie Vandre, Sanitary Engineering Branch, California Department of Health Services, all performed outstanding jobs as resource persons, consultants and advisers. Larry Hannah served as Educational Consultant. Illustrations were drawn by Martin Garrity. Charlene Arora helped type the field test and final manuscript for printing. Special thanks are well deserved by the Program Administrator, Gay Kornweibel, who typed, administered the field test, managed the office, administered the budget, and did everything else that had to be done to complete this project successfully.

KENNETH D. KERRI
PROJECT DIRECTOR

1983

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[1] *Certification examination. An examination administered by a state or professional association that water supply system operators take to indicate a level of professional competence. In many states certification of water supply system operators is voluntary. Current trends indicate that more states and employers will require water supply system operators to be "certified" in the future.*

PREFACE TO THE SECOND EDITION

SMALL WATER SYSTEM OPERATION AND MAINTENANCE is the title of this portion of the Second Edition. When the First Edition, **WATER SUPPLY SYSTEM OPERATION,** was developed, the objective was to produce one comprehensive training manual for water supply system operators. The resulting manual covered all aspects of water supply systems from the source of the water supply to the consumer's tap. Operators using the First Edition, **WATER SUPPLY SYSTEM OPERATION,** expressed a valid concern that too much material was covered in one training manual. In response to this concern the manual was split approximately in half to produce the Second Edition as two manuals:

- **SMALL WATER SYSTEM OPERATION AND MAINTENANCE,** and
- **WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE.**

SMALL WATER SYSTEM OPERATION AND MAINTENANCE contains information on the responsibilities of being an operator, water sources, wells, small water treatment plants, disinfection, safety, lab procedures and a new chapter on rates. **WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE** describes the responsibilities of being an operator, storage facilities, distribution systems, water quality considerations, distribution system operation and maintenance, disinfection and safety. The chapters on disinfection and safety are in both manuals because of their extreme importance. Both of these operator training manuals are equally important if you are responsible for a water supply system. If your agency is large enough to employ two or more crews of operators, the crews may specialize in a particular aspect of operation and maintenance. For example, one crew may deal primarily with wells and disinfection, while the other crew is assigned the responsibility of the distribution system. The splitting of the original manual, **WATER SUPPLY SYSTEM OPERATION,** into two manuals will allow operators to concentrate their studies on the subject areas related directly to their jobs. At the same time, it is hoped that operators will realize the importance of understanding all aspects of water supply systems and attempt to successfully complete both of the manuals.

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1987

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OBJECTIVES OF THIS MANUAL

Proper installation, inspection, operation, maintenance, repair, and management of small water systems have a significant impact on the operation and maintenance costs and effectiveness of the systems. The objective of this manual is to provide small water system operators with the knowledge and skills required to operate and maintain these systems effectively, thus eliminating or reducing the following problems:

1. Health hazards created by the delivery of unsafe water to the consumer's tap;
2. System failures that result from the lack of proper installation, inspection, preventive maintenance, surveillance and repair programs designed to protect the public investment in these facilities;
3. Tastes and odors caused by water system problems;
4. Corrosion damages to pipes, equipment, tanks and structures in the water system;
5. Complaints from the public or local officials due to the unreliability or failure of the water system to perform as designed; and
6. Fire damage caused by insufficient water and/or inadequate pressures at a time of need.

SCOPE OF THIS MANUAL

Operators with the responsibility for wells, pumps, disinfection and small water treatment plants will find this manual very helpful. This manual contains information on:

1. What small water system operators do,
2. Sources and uses of water,
3. How to operate and maintain wells and pumps,
4. Operation and maintenance of small water treatment plants,
5. Disinfection of new and repaired facilities as well as water delivered to consumers,
6. Techniques for recognizing hazards and developing safe procedures and safety programs,
7. Laboratory procedures for analyzing samples of water, and
8. Procedures to develop a reasonable rate structure.

Material in this manual furnishes you with information concerning situations encountered by most small water system operators in most areas. These materials provide you with an understanding of the basic operational and maintenance concepts for small water systems and with an ability to analyze and solve problems when they occur. Operation and maintenance programs for small water systems will vary with the age of the system, the extent and effectiveness of previous programs, and local conditions. You will have to adapt the information and procedures in this manual to your particular situation.

Technology is advancing very rapidly in the field of operation and maintenance of small water systems. To keep pace with scientific advances, the material in this program must be periodically revised and updated. This means that you, the small water system operator, must be aware of new advances and recognize the need for continuous personal training reaching beyond this program. ***TRAINING OPPORTUNITIES EXIST IN YOUR DAILY WORK EXPERIENCE, FROM YOUR ASSOCIATES, AND FROM ATTENDING MEETINGS, WORKSHOPS, CONFERENCES AND CLASSES.***

TECHNOLOGY

WATER SUPPLY SYSTEM OPERATION

USES OF THIS MANUAL

This manual was developed to serve the needs of operators in several different situations. The format used was developed to serve as a home-study or self-paced instruction course for operators in remote areas or persons unable to attend formal classes either due to shift work, personal reasons or the unavailability of suitable classes. This home-study training program uses the concepts of self-paced instruction where you are your own instructor and work at your own speed. In order to certify that a person has successfully completed this program, an objective test is included at the end of each chapter.

Also, this manual can serve effectively as a textbook in the classroom. Many colleges and universities have used similar manuals as texts in formal classes (often taught by operators). In areas where colleges are not available or are unable to offer classes in the operation of small water systems, operators and utility agencies can join together to offer their own courses using the manual.

Cities or utility agencies can use the manual in several types of on-the-job training programs. In one type of program, a manual is purchased for each operator. A senior operator or a group of operators are designated as instructors. These operators help answer questions when the persons in the training program have questions or need assistance. The instructors grade the objective tests at the end of each chapter, record scores and notify California State University, Sacramento, of the scores when a person successfully completes this program. This approach eliminates any waiting while papers are being graded and returned by CSUS.

This manual was prepared to help operators operate and maintain their small water systems. Please feel free to use the manual in the manner which best fits your training needs and the needs of other operators. We will be happy to work with you to assist you in developing your training program. Please feel free to contact:

Ken Kerri, Project Director
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INSTRUCTIONS TO PARTICIPANTS IN HOME-STUDY COURSE

Procedures for reading the lessons and answering the questions are contained in this section.

To progress steadily through this program, you should establish a regular study schedule. For example, many operators in the past have set aside two hours during two evenings a week for study.

The study material is contained in eight chapters. Some chapters are longer and more difficult than others. For this reason, many of the chapters are divided into two or more lessons. The time required to complete a lesson will depend on your background and experience. Some people might require an hour to complete a lesson and some might require three hours; but that is perfectly all right. *THE IMPORTANT THING IS THAT YOU UNDERSTAND THE MATERIAL IN THE LESSON!*

Each lesson is arranged for you to read a short section, write the answers to the questions at the end of the section, check your answers against suggested answers; and then *YOU* decide if you understand the material sufficiently to continue or whether you should read the section again. You will find that this procedure is slower than reading a normal textbook, but you will remember much more when you have finished the lesson.

At the end of each chapter, you will find an "objective test." Mark your answers on the special answer sheet provided for each chapter. Some discussion and review questions are provided following each lesson in the later chapters. These questions review the important points you have covered in the lesson.

The objective test at the end of each lesson contains true or false, multiple-choice, fill-in-the-blank, or match-the-answers types of questions. The purposes of this exam are to review the chapter and to give experience in taking different types of exams. *MAIL TO THE PROGRAM DIRECTOR ONLY YOUR ANSWERS TO OBJECTIVE TESTS ON THE PROVIDED ANSWER SHEETS.*

After you have completed the last objective test, you will find a final examination. This exam is provided for you to review how well you remember the material. You may wish to review the entire manual before you take the final exam. Some of the questions are essay-type questions which are used by some states for higher-level certification examinations. After you have completed the final examination, grade your own paper and determine the areas in which you might need additional review before your next certification or civil service examination.

You are your own teacher in this program. You could merely look up the suggested answers from the answer sheet or copy them from someone else, but you would not understand the material. Consequently, you would not be able to apply the material to the operation of your facilities nor recall it during an examination for certification or a civil service position.

YOU WILL GET OUT OF THIS PROGRAM WHAT YOU PUT INTO IT.

SUMMARY OF PROCEDURE

A. OPERATOR (YOU)

1. Read what you are expected to learn in each chapter (the chapter objectives).
2. Read sections in the lesson.
3. Write your answers to questions at the end of each section in your notebook. You should write the answers to the questions just as you would if these were questions on a test.
4. Check your answers with the suggested answers.
5. Decide whether to reread the section or to continue with the next section.
6. Write your answers to the discussion and review questions at the end of each lesson in your notebook.
7. Mark your answers to the objective test on the answer sheet provided by the Project Director or by your instructor.

8. Mail material to the Project Director. (Send *ONLY* your completed answer sheet.)

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Water Supply System Operation
California State University, Sacramento
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Sacramento, California 95819-2694

B. PROJECT DIRECTOR

1. Mails answer sheet for each chapter to operator.
2. Corrects tests, answers any questions, and returns results to operators.

C. ORDER OF WORKING LESSONS

To complete this program you will have to work all of the lessons. You may proceed in numerical order, or you may wish to work some lessons sooner.

SAFETY IS A VERY IMPORTANT TOPIC. Everyone working in a small water system must always be safety conscious. Operators daily encounter situations and equipment that can cause a serious disabling injury or illness if the operator is not aware of the potential danger and does not exercise adequate precautions. For these reasons, you may decide to work on Chapter 6, "Safety" early in your studies. In each chapter, SAFE PROCEDURES ARE ALWAYS STRESSED.

THINK SAFETY!

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COURSE OUTLINE

WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE

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COURSE OUTLINE

SMALL WATER SYSTEM OPERATION AND MAINTENANCE

(Wells, Small Treatment Plants, and Rates)

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CHAPTER 1

THE SMALL WATER SYSTEM OPERATOR

by

Ken Kerri

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OBJECTIVES

Chapter 1. THE SMALL WATER SYSTEM OPERATOR

At the beginning of each chapter in this manual you will find a list of *OBJECTIVES*. The purpose of this list is to stress those topics in the chapter that are most important. Contained in the list will be items you need to know and skills you must develop to operate, maintain, repair and manage a small water system as efficiently and as safely as possible.

Following completion of Chapter 1 you should be able to:

1. Explain the type of work done by small water system operators.
2. Describe where to look for jobs in this profession, and
3. Find sources of further information on how to do the jobs performed by small water system operators.

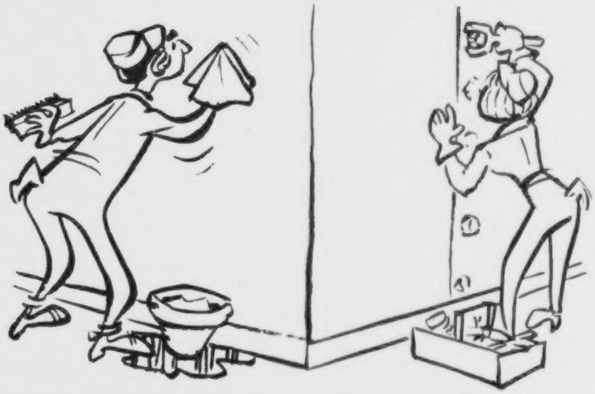
CHAPTER 1. THE SMALL WATER SYSTEM OPERATOR

Chapter 1 is prepared especially for new operators or people interested in becoming small water system operators. If you are an experienced small water system operator, you may find some new viewpoints in this chapter.

In these training manuals, the water supply system has been divided into two parts: (1) the water system and (2) the water distribution system. The water system begins with the source of water such as groundwater or surface water. Wells, pumps and treatment facilities are part of the water system which delivers water to the distribution system. The water distribution system consists of tanks and pipes which store and deliver treated water to the consumers.

1.0 NEED FOR SMALL WATER SYSTEM OPERATORS

People need safe and pleasant water to drink. Many sources of water are not directly suitable for drinking purposes. Engineers have designed water supply facilities to collect, store, transport, treat and distribute water to people and industries. Once these facilities are built, the operators make the facilities do their intended job. Small water system operators operate, maintain, repair and manage these facilities. Operators have the responsibility of insuring that safe and pleasant drinking water is delivered to everyone's tap. Another responsibility is to be sure that adequate amounts of water and pressure are available during times of emergency, such as a fire. Cities and towns need qualified, capable and dedicated operators to do these jobs.



The need for *RESPONSIBLE* small water system operators cannot be overstressed. You, as a small water system operator, have the responsibility for the health and well being of the community you serve. Yes, you are responsible for the drinking water of your community and anytime you fail to do your job, you could be responsible for an outbreak of a water-borne disease which could even result in death. As an operator, you do not want the knowledge that you were negligent in your duty and, as a result, were responsible for the death of a fellow human being.

QUESTIONS

Below are some questions for you to answer. You should have a notebook in which you can write the answers to the questions. By writing down the answers to the questions, you are helping yourself learn and retain the information. After you have answered all the questions, compare your answers with those given in the Suggested Answers section on page 10. Reread any sections you do not understand and then proceed to the next section. You are your own teacher in this training program, and *YOU* should decide when you understand the material and are ready to continue with new material.

1.0A What is the responsibility of small water system operators?

1.0B What do small water system operators do with small water facilities?

1.1 WHAT IS A WATER SUPPLY SYSTEM?

1.10 Sources of Water

A water supply system delivers water from its source to the ultimate consumer — homes, businesses or industrial water users (Fig. 1.1). The source of a water supply may be either groundwater or surface waters. Surface waters may be natural lakes, streams, rivers or reservoirs behind dams. Groundwater is a water source below the ground surface.

Water is usually transported from its source through a transmission system consisting of either open channels (canals) or large-diameter pipes (called raw water conduits) to the water treatment plant. After treatment the water is usually pumped into transmission lines which are connected to a distribution grid system. From the grid system the water is delivered to individual service lines which serve private homes, businesses, factories and industries. Groundwaters may not have transmission lines, but are often disinfected with chlorine and pumped directly to service storage and distribution systems.

1.11 Storage Facilities

Storage facilities may consist of large reservoirs behind dams (impoundments) or service storage reservoirs located at water treatment plants and/or at various places in distribution systems. Storage facilities for treated water at water treatment plants are called clear wells. Operational service storage tanks in distribution systems may be pressure tanks, elevated tanks, ground-level tanks or reservoirs, or underground facilities.

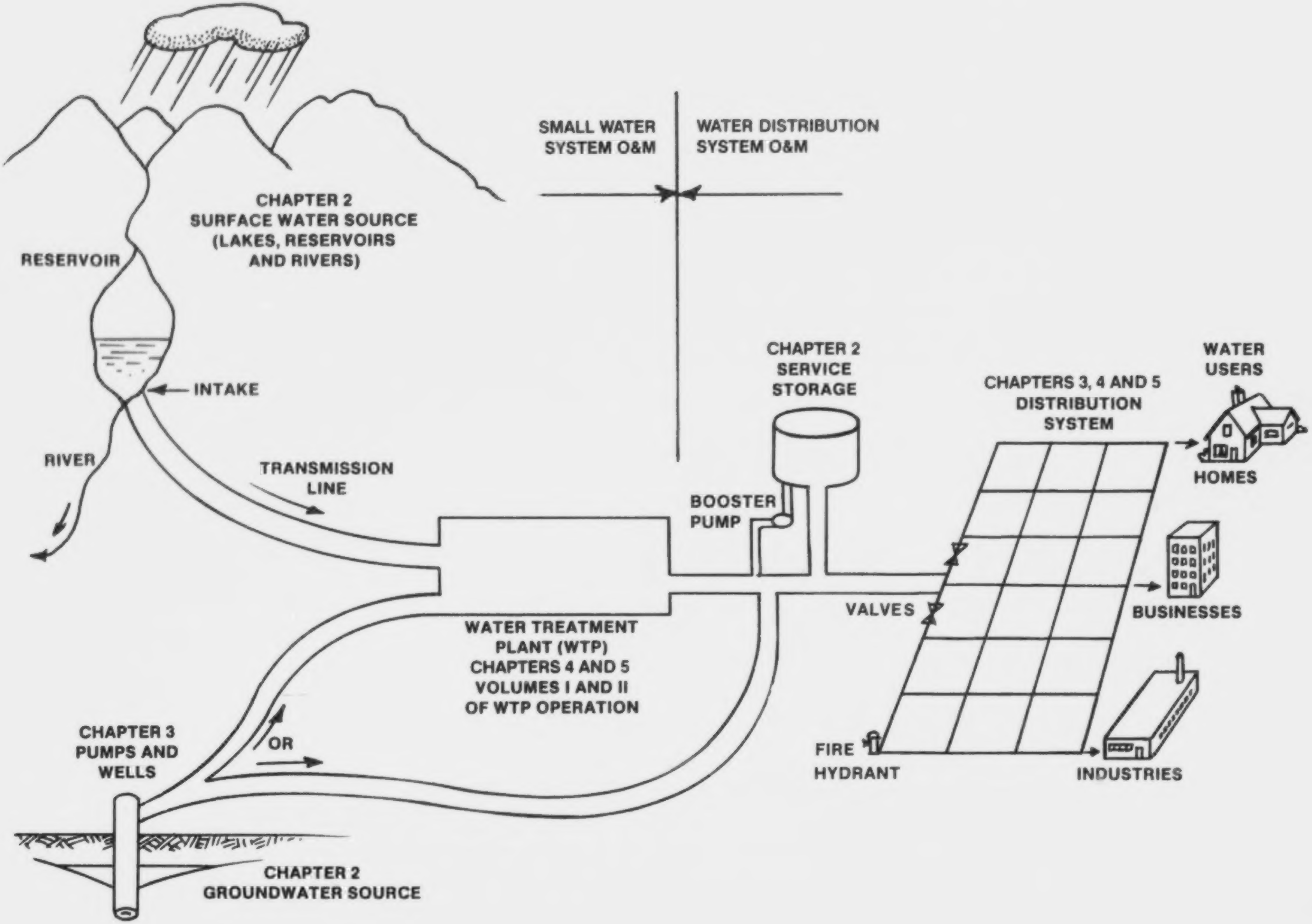

SMALL WATER SYSTEM O&M
WATER DISTRIBUTION SYSTEM O&M
CHAPTER 2 SURFACE WATER SOURCE (LAKES, RESERVOIRS AND RIVERS)
RESERVOIR
INTAKE
RIVER
TRANSMISSION LINE
CHAPTER 2 SERVICE STORAGE
BOOSTER PUMP
CHAPTERS 3, 4 AND 5 DISTRIBUTION SYSTEM
WATER USERS
HOMES
BUSINESSES
VALVES
INDUSTRIES
FIRE HYDRANT
WATER TREATMENT PLANT (WTP) CHAPTERS 4 AND 5 VOLUMES I AND II OF WTP OPERATION
CHAPTER 3 PUMPS AND WELLS
OR
CHAPTER 2 GROUNDWATER SOURCE

Fig. 1.1 Typical water supply system

1.12 Treatment Facilities

Surface waters require treatment to remove suspended and dissolved materials and also to kill disease-causing organisms. Groundwater may require treatment for the removal of excessive hardness, taste- and odor-causing substances, dissolved gases, and impurities such as iron and manganese. Water treatment plants provide the necessary treatment to make the waters safe and suitable for drinking purposes. All waters, regardless of source or treatment received, should be disinfected to prevent the spread of disease-causing organisms. Chlorination is the most common means of disinfection used today to protect the public's health.

1.13 Distribution Systems

A distribution system consists of a network of pipes, valves, fire hydrants, service lines, meters, and pumping stations. The system delivers water to homes, businesses and industries for drinking and other uses. This water also is used for fire protection. The network of pipes, pumping stations, and service storage reservoirs must have sufficient capacity to meet maximum water demands plus fire-fighting requirements and still maintain adequate water pressures throughout the water distribution system. Valves are necessary to isolate portions of the distribution system for cleaning, maintenance, repairs, and making additions to the system. The distribution system should be free of cross-connections with unapproved water supplies which could allow contamination to be introduced into the system.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 10.

1.1A List the two major sources of water supplies.

1.1B Why should surface waters be treated?

1.2 WHAT DOES A SMALL WATER SYSTEM OPERATOR DO?

1.20 Operation and Maintenance

Simply described, small water system operators keep the system operating efficiently to deliver safe and pleasant water. They inspect the system to keep the water flowing today and in the future. Physically, they have manual and power-operated equipment to help them do the job, including repairs and minor additions to the system. Other jobs include lubricating and maintaining equipment, collecting water samples and recordkeeping. Typical duties performed by small water system operators are summarized in Table 1.1

To describe your duties in detail, let's start at the beginning. Let us say that the need for new wells and pumps, and also for new or improved storage tanks and distribution pipe network has long been recognized by your community. The community has voted to issue the necessary bonds to finance the project, and the consulting engineers have been requested to submit plans and specifications. In the best interests of the community and the consulting engineer, you should be in on the ground floor planning and design.

You and the engineer should discuss the proposed locations and layout of wells, service reservoirs and pipe networks. Your job is to discuss with the engineer how these new facilities could be operated, maintained and repaired and also to make suggestions on how these jobs could be done more easily. Be sure there is adequate room for maintenance and repair equipment even during adverse weather conditions. Together with the consulting engineers, you can be a member of an expert team able to advise your water utility.

TABLE 1.1 TYPICAL DUTIES OF A SMALL WATER SYSTEM OPERATOR

1. Place barricades, signs, and traffic cones around work sites to protect operators and public.
2. Excavate trenches and install shoring.
3. Lay, connect, test and disinfect water mains.
4. Tap into water mains.
5. Flush and clean water mains.
6. Read and update water distribution system maps and "as built" plans.
7. Operate and maintain well pumps and hydropneumatic pressure tanks.
8. Collect and transport water samples.
9. Clean and disinfect storage tanks and reservoirs.
10. Protect water mains and storage facilities from corrosion effects.
11. Observe pump motors to detect unusual noises, vibrations, or excessive heat.
12. Adjust and clean pump seals and packing glands and also clean mechanical seals.
13. Repair and overhaul pumps, motors, chlorinators, and control valves.
14. Safely load and unload chlorine cylinders and other dry and liquid chemicals.
15. Keep records and prepare reports.
16. Estimate and justify budget requests for supplies and equipment.
17. Start up or shut down pumps as necessary to regulate system flows and pressures.
18. Perform efficiency tests on pumps and related equipment.
19. Troubleshoot minor electrical and mechanical equipment problems and correct.
20. Detect hazardous atmospheres and correct before entry.
21. Conduct safety inspections, follow safety rules for waterworks facilities, and also develop and conduct tailgate safety meetings.
22. Troubleshoot to locate the causes of water quality complaints.
23. Discuss with the public their concerns regarding the quality of the water they receive.
24. Communicate effectively with other operators and supervisors on the technical level expected for your position.

Ultimately you want to operate your pumps and reservoirs in such a fashion that your consumers will always have sufficient, safe and pleasant water at adequate pressures.

1.21 Supervision and Administration

In addition to operation and maintenance duties for your small water system, you may also be responsible for supervision of personnel. Chief operators or supervisors frequently have the responsibility of training new operators and should encourage all operators to strive for higher levels of certification.

As a small water system administrator, you may be in charge of recordkeeping. In this case, you will be responsible for operating and maintaining the system as efficiently as possible, keeping in mind that the primary objective is to deliver safe and pleasant drinking water to your consumers. Without adequate, reliable records of important phases of operation and maintenance, the effectiveness of your operation has not been documented (recorded). Also, accurate records are required by regulatory agencies in accordance with the Drinking Water Regulations of the Safe Drinking Water Act.

You may also be the budget administrator. Here you will be in the best position to give advice on budget requirements, management problems, and future planning. You should be aware of the necessity for additional expenditures, including funds for new facilities and enlargement of existing facilities, equipment replacement, and additional employees. You should recognize these and define them clearly for the proper officials. Early planning and budgeting of this type will contribute greatly to the continued smooth operation of your facility.

1.22 Public Relations

As an operator you are in the field of public relations and must be able to explain the purpose and operation of your facilities to civic organizations, school classes, representatives of news media, and even to city council members or directors of your district. Lots of people want to know about the large elevated storage tank or those "funny things" sticking out the top of an underground storage reservoir. One of the best results from a well-guided tour is gaining support from your city council and the public to obtain the funds necessary to run a good operation.

The overall appearance of your pump stations and elevated tanks indicates to the public the type of operation you maintain. If the facilities are dirty and rundown, in need of painting, and overgrown with weeds, you will be unable to convince the public that you are doing a good job. *YOUR RECORDS SHOWING THAT YOU ARE DELIVERING SAFE DRINKING WATER TO YOUR CONSUMERS WILL MEAN NOTHING TO VISITORS AND NEIGHBORS OF YOUR FACILITIES UNLESS YOUR FACILITIES APPEAR CLEAN AND WELL MAINTAINED.*

Another aspect of your job may be handling complaints. When someone contacts you complaining that their drinking water looks muddy, tastes bad or smells bad, you may have a serious problem. Whenever someone complains, record all of the necessary information (name, date, location, and phone number) and have the complaint thoroughly investigated. Be sure to notify the person who complained of the results of your investigation and what corrective action was or will be taken.

SAFETY FIRST!
WATCH YOUR STEP!
Think Safety
IF IN DOUBT DON'T!
SAFETY

1.23 Safety

Safety is a very important operator responsibility. Unfortunately, too many small water system operators take safety for granted. *YOU* have the responsibility to be sure that your facilities are a safe place to work and that everyone follows safe procedures. Everyone must follow safe procedures and understand why safe procedures must be followed at all times. All operators must be aware of safety hazards in and around water system facilities. Work in traffic and excavating for the installation or repair of pipes can be extremely hazardous. Explosive conditions can develop when painting the inside of an elevated tank if adequate ventilation is not provided. Most accidents result from carelessness or negligence. You should plan or be a part of an active safety program. Also, you may have the responsibility of training new operators and safe procedures must be stressed.

Clearly, the modern day small water system operator must be capable of doing many jobs — *AND DOING THEM ALL SAFELY.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 10.

1.2A Why should small water system operators discuss proposed facilities with engineers?

1.2B Why are adequate and reliable records very important?

1.2C To whom might you have to explain the purpose and operation of your facilities?

1.2D Why is the appearance of pump stations and elevated tanks and the grounds around them important?

1.2E Why is safety important?

1.3 JOB OPPORTUNITIES

1.30 Manpower Needs

The small water system field is changing rapidly. New facilities and systems are being constructed, and old facilities and systems are being modified and enlarged to meet the water system demands of our growing population and industries. Towns, municipalities, special districts and industries all employ water system operators. Operators, maintenance personnel, foremen, managers, instrumentation experts, and laboratory technicians are sorely needed now and will be in the future.

1.31 Who Hires Small Water System Operators?

Operators' paychecks usually come from a city, water agency or district, or a private utility company. The operator also may be employed by one of the many large industries which operate their own water system. As an operator, you are always responsible to your employer for operating and maintaining an economical and efficient water system. An even greater obligation rests with the operator because of the great number of people who drink the water from the distribution system. In the final analysis, the operator is really working for the people who depend on the operator to provide them with safe and pleasant drinking water.

1.32 Where Do Small Water System Operators Work?

Jobs are available for small water system operators wherever people live and need someone to deliver water to their homes, offices or industrial processes. The different types and locations of small water systems offer a wide range of working conditions. From the mountains to the sea, wherever people gather together into communities, small water systems will be found. From a small system foreman or a computer control center operator at a complex municipal storage and distribution system to a one-person manager of a small town water supply system, you can select your own special place in water system operation.

1.33 What Pay Can a Small Water System Operator Expect?

In dollars? Prestige? Job satisfaction? Community service? In opportunities for advancement? By whatever scale you use, returns are mainly what you make them. If you choose a large municipality, the pay is good and advancement prospects are tops. Choose a small town and the pay may not be as good, but job satisfaction, freedom from time-clock hours, community service, and prestige may well add up to a more desirable outstanding personal achievement. If you have the ability and take advantage of the opportunities, you can make this field your career and advance to an enviable position. Many of these positions are or will be represented by an employee organization that will try to obtain higher pay and other benefits for you. Total reward depends on you and how *YOU APPLY YOURSELF.*

Satisfaction
Prestige
DOLLARS
COMMUNITY SERVICES
Advancement
OPPORTUNITIES

1.34 What Does It Take To Be a Small Water System Operator?

DESIRE. First you must make the serious decision to enter this fine profession. You can do this with a high school or a college education. While some jobs will always exist for manual labor, the real and expanding need is for *QUALIFIED OPERATORS.* You must be willing to study and take an active role in upgrading your capabilities. New techniques, advanced equipment, and increasing use of complex instrumentation and computers require a new breed of small water system operator: one who is willing to learn today, and gain tomorrow, for surely your small water system will move towards newer and more effective operation and maintenance procedures. Indeed, the truly service-minded operator assists in adding to and improving the performance of the small water system on a continuing basis.

You can be a small water system operator tomorrow by beginning your learning today; or you can be a better operator, ready for advancement, by accelerating your learning today.

This training course, then, is your start towards a better tomorrow, both for you and for the public who will receive better water from your efforts.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 10.

1.3A Who hires small water system operators?

1.3B What does it take to be a good small water system operator?

1.4 PREPARING YOURSELF FOR THE FUTURE

1.40 Your qualifications

What do you know about your job or the job you'd like to obtain? Perhaps a little, and perhaps a lot. You must evaluate the knowledge, skills and experience you already have and what you will need to achieve future jobs and advancement.

The knowledge and skills required for your job depend to a large degree on the size and type of water system where you work. You may work on a large, complex system serving several hundred or more operators. In this case, you are probably a specialist in one of more phases of the distribution system or storage reservoirs (such as being responsible for the valves).

On the other hand, you may operate and maintain a small water system serving only a thousand people or even fewer. You may be the only operator, for the entire system or, at best, have only one or two helpers. If this is the case, you must be a "jack-of-all-trades" because of the diversity of your tasks.

1.41 Your Personal Training Program

Beginning on this page you are starting a training course which has been carefully prepared to help you to improve your knowledge and skills to operate and maintain small water systems.

You will be able to proceed at your own pace; you will have the opportunity to learn a little or a lot about each topic. This training manual has been prepared this way to meet the various needs of small water system operators, depending on the size and type of system for which you are responsible. To study for certification and civil service exams, you may have to cover most of the material in this manual. You will never know everything about small water systems and the equipment and procedures available for operation and maintenance. However, you will be able to answer some very important questions about how, why, and when certain things happen in small water systems. You can also learn how to manage your small water system to provide a reliable supply of safe and pleasant drinking water to your customers while minimizing costs in the long run.

This training course is not the only one available to help you improve your abilities. Some state water utility associations, vocational schools, community colleges, and universities offer training courses on both a short- and long-term basis. Many state, local and private agencies have conducted training programs and informative seminars. Most state health departments can be very helpful in providing training programs or directing you to good programs.

Some libraries can provide you with useful journals and books on small water systems. Listed below are several very good references in the field of small water systems. Prices listed were those available when this manual was published; they will probably increase in the future.

1. *A MANUAL OF INSTRUCTION FOR WATER TREATMENT PLANT OPERATORS.* Available from Health Education Service, Inc., P. O. Box 7126, Albany, New York 12224. Price $3.13.
2. *MANUAL OF WATER UTILITY OPERATIONS.* Available from Texas Water Utilities Association, 6521 Burnet Lane, Austin, Texas 79757. Price $17.00.
3. *WATER DISTRIBUTION OPERATOR TRAINING HANDBOOK,* Order No. 20103. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to members, $13.00; nonmembers, $16.50.
4. *INTRODUCTION TO WATER SOURCES AND TRANSMISSION,* Volume I, Order No. 1901. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price $10.00.
5. *INTRODUCTION TO WATER DISTRIBUTION,* Volume 3, Order No. 1916. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price $27.50.
6. *STUDY GUIDE TO THE ABC TESTING SERVICE FOR WATER TREATMENT PLANT AND DISTRIBUTION SYSTEM OPERATORS,* Association of Boards of Certification (ABC), P. O. Box 2266, Ames, Iowa 50010. Price $14.00.

Throughout this manual we will be recommending American Water Works (AWWA) publications. Members of AWWA can buy some publications at reduced prices. You can join AWWA by writing to the headquarters office in Denver or by contacting a member of AWWA. Headquarters can help you contact your own state or regional AWWA Section. This professional organization can offer you many helpful training opportunities and educational materials when you join and actively participate with your associates in the field.

1.42 Certification

Certification examinations are usually administered by state regulatory agencies or professional associations. Operators take these exams in order to obtain certificates which indicate a level of professional competence. You should continually strive to achieve higher levels of certification. Successful completion of this operator training program will help you achieve your certification goals.

1.5 ACKNOWLEDGMENTS

Many of the topics and ideas discussed in this chapter were based on similar work written by Larry Trumbull and Walt Driggs.

SUGGESTED ANSWERS

Chapter 1. THE SMALL WATER SYSTEM OPERATOR

You are not expected to have the exact answers suggested for questions requiring written answers, but you should have the correct idea. The numbering of the questions refers to the section in the chapter where you can find the information to answer the questions. Answers to questions numbered 1.0A and 1.0B can be found in Section 1.0, "Need for Small Water System Operators."

Answers to questions on page 4.

1.0A Small water system operators have the responsibility of insuring that safe and pleasant drinking water is delivered to everyone's tap. Also adequate amounts of water and pressure must be available during times of emergency, such as a fire.

1.0B Small water system operators make sure small water system facilities do their intended job. Operators operate, maintain, repair and manage these facilities.

Answers to questions on page 6.

1.1A The two major sources of water supplies are (1) groundwater and (2) surface water.

1.1B Surface water is usually treated to remove suspended and dissolved materials and to kill disease-causing organisms.

Answers to questions on page 7.

1.2A Small water system operators should discuss proposed facilities with engineers to find out how the engineer intends for these facilities to be operated, maintained and repaired and also to make suggestions on how these jobs could be done more easily. Be sure there is adequate room for maintenance and repair equipment even during adverse weather conditions.

1.2B Adequate and reliable records are very important to document the effectiveness of your operation.

1.2C Small water system operators must be able to explain the purpose and operation of their facilities to civic organizations, school classes, representatives of news media, and even to city council members or directors of their district.

1.2D The appearance of pump stations and elevated tanks and the grounds around them indicates to the public the type of operation you maintain.

1.2E Safety is a very important operator responsibility. Most accidents result from carelessness or negligence. Safe procedures must be stressed at all times.

Answers to questions on page 8.

1.3A Small water system operators may be hired by cities, water agencies or districts, private utility companies or industries.

1.3B *DESIRE*, if you want to be a qualified small water system operator, you can do it.

WATER DISTRIBUTION SYSTEM O & M

IMPORTANT

PLEASE READ INSTRUCTIONS ON REVERSE SIDE BEFORE COMPLETING THIS FORM.

OFFICE USE ONLY
DO NOT MARK
●

Name: OPERATOR, JOE B.
Last First MI

Address: 711 MAIN STREET
SAFEWATER, CA 01234
City State Zip Code

Mail to:
Professor Kenneth Kerri
California State University, Sacramento
6000 J Street
Sacramento, California 95819

SOCIAL SECURITY NUMBER									CHAPTER NUMBER	
1	2	3	4	5	6	7	8	9	0	1
0	0	0	0	0	0	0	0	0	●	0
●	1	1	1	1	1	1	1	1	1	●
2	●	2	2	2	2	2	2	2	2	2
3	3	●	3	3	3	3	3	3	3	3
4	4	4	●	4	4	4	4	4		4
5	5	5	5	●	5	5	5	5		5
6	6	6	6	6	●	6	6	6		6
7	7	7	7	7	7	●	7	7		7
8	8	8	8	8	8	8	●	8		8
9	9	9	9	9	9	9	9	●		9

FOLD

IMPORTANT DIRECTIONS FOR MARKING ANSWERS

Use black lead pencil only (# 2 or softer).
Make heavy black marks that fill the circle completely.
Erase clearly any answer you wish to change.
Make no stray marks on this answer sheet.

EXAMPLE

SOCIAL SECURITY NUMBER									CHAPTER NUMBER	
1	2	3	4	5	6	7	8	9	0	1
0	0	0	0	0	0	0	0	0	●	0
●	1	1	1	1	1	1	1	1	1	●
2	●	2	2	2	2	2	2	2	2	2
3	3	●	3	3	3	3	3	3	3	3
4	4	4	●	4	4	4	4	4		4
5	5	5	5	●	5	5	5	5		5
6	6	6	6	6	●	6	6	6		6
7	7	7	7	7	7	●	7	7		7
8	8	8	8	8	8	8	●	8		8
9	9	9	9	9	9	9	9	●		9

1. MULTIPLE CHOICE QUESTIONS: Fill in the correct answers. If 2 and 3 are correct for question 1, mark:

	1	2	3	4	5
1	Ⓣ	●	●	○	○

2. TRUE-FALSE QUESTIONS: If true, fill in the circle in column 1; if false, fill in column 2. If question 3 is true, mark:

	1	2	3	4	5
3	●	Ⓕ	○	○	○

Sample
Do Not Use

NCS Trans-Optic OS 16453 321

FOLD

	1	2	3	4	5
1	Ⓣ	Ⓕ	○	○	○
2	Ⓣ	Ⓕ	○	○	○
3	Ⓣ	Ⓕ	○	○	○
4	Ⓣ	Ⓕ	○	○	○
5	Ⓣ	Ⓕ	○	○	○
6	Ⓣ	Ⓕ	○	○	○
7	Ⓣ	Ⓕ	○	○	○
8	Ⓣ	Ⓕ	○	○	○
9	Ⓣ	Ⓕ	○	○	○
10	Ⓣ	Ⓕ	○	○	○
11	Ⓣ	Ⓕ	○	○	○
12	Ⓣ	Ⓕ	○	○	○
13	Ⓣ	Ⓕ	○	○	○
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15	Ⓣ	Ⓕ	○	○	○
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18	Ⓣ	Ⓕ	○	○	○
19	Ⓣ	Ⓕ	○	○	○
20	Ⓣ	Ⓕ	○	○	○
21	Ⓣ	Ⓕ	○	○	○
22	Ⓣ	Ⓕ	○	○	○
23	Ⓣ	Ⓕ	○	○	○
24	Ⓣ	Ⓕ	○	○	○
25	Ⓣ	Ⓕ	○	○	○
26	Ⓣ	Ⓕ	○	○	○
27	Ⓣ	Ⓕ	○	○	○
28	Ⓣ	Ⓕ	○	○	○
29	Ⓣ	Ⓕ	○	○	○
30	Ⓣ	Ⓕ	○	○	○
31	Ⓣ	Ⓕ	○	○	○
32	Ⓣ	Ⓕ	○	○	○
33	Ⓣ	Ⓕ	○	○	○
34	Ⓣ	Ⓕ	○	○	○
35	Ⓣ	Ⓕ	○	○	○
36	Ⓣ	Ⓕ	○	○	○
37	Ⓣ	Ⓕ	○	○	○
38	Ⓣ	Ⓕ	○	○	○
39	Ⓣ	Ⓕ	○	○	○
40	Ⓣ	Ⓕ	○	○	○
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43	Ⓣ	Ⓕ	○	○	○
44	Ⓣ	Ⓕ	○	○	○
45	Ⓣ	Ⓕ	○	○	○
46	Ⓣ	Ⓕ	○	○	○
47	Ⓣ	Ⓕ	○	○	○
48	Ⓣ	Ⓕ	○	○	○
49	Ⓣ	Ⓕ	○	○	○
50	Ⓣ	Ⓕ	○	○	○
51	Ⓣ	Ⓕ	○	○	○
52	Ⓣ	Ⓕ	○	○	○
53	Ⓣ	Ⓕ	○	○	○
54	Ⓣ	Ⓕ	○	○	○
55	Ⓣ	Ⓕ	○	○	○
56	Ⓣ	Ⓕ	○	○	○
57	Ⓣ	Ⓕ	○	○	○
58	Ⓣ	Ⓕ	○	○	○
59	Ⓣ	Ⓕ	○	○	○
60	Ⓣ	Ⓕ	○	○	○

DIRECTIONS FOR WORKING OBJECTIVE TEST

CHAPTER 1. THE SMALL WATER SYSTEM OPERATOR

1. You have been provided with a special answer sheet (see page 11) for each chapter. Be sure you follow the special directions provided with the answer sheets. If you lose an answer sheet or have any problems, please notify the Project Director.

2. Mark your answers on the answer sheet with a dark lead pencil. Do not use ink. Be certain to mark *ALL* correct answers.

   For example, if Question 2 had three correct answers (1, 2 and 3), you should place a mark under Columns 1, 2 and 3 on the answer sheet.

   Questions 1 through 5 are true or false questions. If a question is true, then mark Column 1, and if false mark Column 2. The correct answer to Question 4 is true; therefore, place a mark in Column 1.

   Please mark your answers in your workbook for your record because answer sheets will not be returned to you.

3. Mail answer sheet to the Project Director immediately after you have completed the test.

4. Answer sheets may be folded (but not into more than 3 equal parts) and mailed in a 4 x 9½ standard white envelope.

OBJECTIVE TEST

CHAPTER 1. THE SMALL WATER SYSTEM OPERATOR

Please mark the correct answers on an answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple-choice questions.

True — False

1. Small water system operators may encounter hazardous conditions when doing their job.
   1. True
   2. False

2. Small water system operators may receive taste and odor complaints.
   1. True
   2. False

3. Most sources of surface waters are suitable for drinking purposes without any treatment.
   1. True
   2. False

4. Distribution systems should be free of valves which can be used to isolate a portion of the system.
   1. True
   2. False

5. Storage facilities for treated water at treatment plants are called "clear wells."
   1. True
   2. False

Multiple Choice

6. In these training manuals the water supply system has been divided into two parts, the

    1. Collection system and the treatment system.
    2. Storage system and the distribution system.
    3. Water system and the collection system.
    4. Water system and the distribution system.
    5. Well system and the treatment system.

7. Operators of small water systems are responsible for

    1. Health and well being of community.
    2. Insuring that safe and pleasant drinking water is delivered to everyone's tap.
    3. Keeping themselves prepared for the future.
    4. Operating and maintaining water systems.
    5. Wells, pumps and treatment facilities.

8. Where can small water system operators look for more information and training courses to improve themselves?

    1. American Water Works Association
    2. Colleges and universities
    3. Health departments
    4. Libraries
    5. Water utilities' associations

9. Water supply distribution systems may consist of

    1. Booster pumps.
    2. Fire hydrants.
    3. Pipelines.
    4. Sewers.
    5. Valves.

10. You must operate and maintain your water supply system to meet

    1. Drinking water regulations.
    2. Fire fighting requirements.
    3. Manpower needs.
    4. Pressure requirements.
    5. Recordkeeping requirements.

11. Typical safety hazards encountered by a water supply system operator on the job include

    1. Careless operator not following safe procedures.
    2. Cave-ins while excavating to repair a pipe.
    3. Drowning while repairing a raw water pipe.
    4. Explosive conditions when painting the inside of an elevated tank.
    5. Traffic while repairing a broken water main.

12. A water supply system operator may be expected to

    1. Inspect the distribution system
    2. Handle complaints.
    3. Lubricate pumps.
    4. Maintain service storage tanks.
    5. Prepare and administer budgets.

END OF OBJECTIVE TEST

Chapter 2

WATER SOURCES AND TREATMENT

by

Bert Ellsworth

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OBJECTIVES

Chapter 2. WATER SOURCES AND TREATMENT

Following completion of Chapter 2, you should be able to:

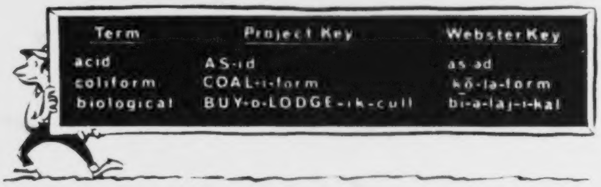
1. Describe the importance of water,
2. Identify various sources of water,
3. Outline the procedures of a sanitary survey,
4. Evaluate the suitability of a water source for drinking purposes and as a general water supply, and
5. Identify water quality problems and treatment processes to solve the problems.

OPERATOR'S PROJECT PRONUNCIATION KEY

by Warren L. Prentice

The Project Pronunciation Key is designed to aid you in the pronunciation of new words. While this Key is based primarily on familiar sounds, it does not attempt to follow any particular pronunciation guide. This Key is designed solely to aid operators in this program.

You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation Key. Each Key will be different from each other and from this Key. Examples of the differences between the Key used in this program and the *WEBSTER'S NEW WORLD DICTIONARY* "Key" are shown below:



Term	Project Key	Webster Key
acid	AS-id	as·ad
coliform	COAL-i-form	kō-la-form
biological	BUY-o-LODGE-ik-cull	bi-a-laj-i-kal

In using this Key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	Syllable				
	1st	2nd	3rd	4th	5th
Word					
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word *ACID* has its first syllable accented. The second word, *COAGULANT*, has its second syllable accented. The third word, *BIOLOGICAL*, has its first and third syllables accented.

We hope you will find the Key useful in unlocking the pronunciation of any new word.

---

[1] *The WEBSTER'S NEW WORLD DICTIONARY, Second College Edition, 1972, was chosen rather than an unabridged dictionary because of its availability to the operator. Other editions may be slightly different.*

GLOSSARY

Chapter 2. WATER SOURCES AND TREATMENT

ACID RAIN ACID RAIN

Precipitation which has been rendered (made) acidic by airborne pollutants.

APPROPRIATIVE APPROPRIATIVE

Water rights to or ownership of a water supply which is acquired for the beneficial use of water by following a specific legal procedure.

AQUIFER (ACK-wi-fer) AQUIFER

A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

ARTESIAN (are-TEE-zhun) ARTESIAN

Pertaining to groundwater, a well, or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given the opportunity to do so.

CAPILLARY FRINGE CAPILLARY FRINGE

The porous material just above the water table which may hold water by capillarity (a property of surface tension that draws water upwards) in the smaller void spaces.

CISTERN (SIS-turn) CISTERN

A small tank (usually covered) or a storage facility used to store water for a home or farm.

CONTAMINATION CONTAMINATION

The introduction into water of microorganisms, chemicals, toxic materials, wastes or wastewater in a concentration that makes the water unfit for its next intended use.

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

DIRECT RUNOFF DIRECT RUNOFF

Water that flows over the ground surface or through the ground directly into streams, rivers, or lakes.

DRAWDOWN DRAWDOWN

The drop in the water table or level of water in the ground when water is being pumped from the well.

EPIDEMIOLOGY (EP-uh-DEE-me-ALL-o-gee) EPIDEMIOLOGY

A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.

EVAPORATION EVAPORATION

The process by which water or other liquid becomes a gas (water vapor or ammonia vapor).

EVAPOTRANSPIRATION (ee-VAP-o-TRANS-purr-A-shun) EVAPOTRANSPIRATION

The process by which water vapor passes into the atmosphere from living plants. Also called TRANSPIRATION.

GEOLOGICAL LOG GEOLOGICAL LOG

A detailed description of all underground features discovered during the drilling of a well (depth, thickness and type of formations).

HYDROLOGIC CYCLE (HI-dro-LOJ-ic) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean. Also called the WATER CYCLE.

IMPERMEABLE (im-PURR-me-uh-BULL) IMPERMEABLE

Not easily penetrated. The property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water.

INFILTRATION (IN-fill-TRAY-shun) INFILTRATION

The gradual flow or movement of water into and through (to percolate or pass through) the pores of the soil. Also called PERCOLATION.

MICROORGANISMS (MY-crow-OR-gan-IS-zums) MICROORGANISMS

Living organisms that can be seen individually only with the aid of a microscope.

NONPOTABLE (non-POE-tuh-bull) NONPOTABLE

Water that may contain objectionable pollution, contamination, minerals, or infective agents and is considered unsafe and/or unpalatable for drinking.

PALATABLE (PAL-a-ta-ble) PALATABLE

Water at a desired temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

PATHOGENIC ORGANISMS (path-o-JEN-nick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of organisms which do *NOT* cause disease. These organisms are called non-pathogenic.

POLLUTION POLLUTION

The impairment (reduction) of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes), to a degree that has an adverse effect on any beneficial use of water.

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

PRECIPITATION (pre-SIP-i-TAY-shun) PRECIPITATION

The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, and other forms of moisture.

PRESCRIPTIVE (pre-SKRIP-tive) PRESCRIPTIVE

Water rights which are acquired by diverting water and putting it to use in accordance with specified procedures. These procedures include the filing of a request to use unused water in a stream, river or lake with a state agency.

RAW WATER RAW WATER

(1) Water in its natural state, prior to any treatment.
(2) Usually the water entering the first treatment process of a water treatment plant.

RIPARIAN (ri-PAIR-i-an) RIPARIAN

Water rights which are acquired together with title to the land bordering a source of surface water. The right to put to beneficial use surface water adjacent to your land.

SAFE DRINKING WATER ACT (SDWA) SAFE DRINKING WATER ACT (SDWA)

Commonly referred to as SDWA. An Act passed by the US Congress in 1974. The Act establishes a cooperative program among local, state and federal agencies to insure safe drinking water for consumers.

SAFE WATER SAFE WATER

Water that does not contain harmful bacteria, or toxic materials or chemicals. Water may have taste and odor problems, color and certain mineral problems and still be considered safe for drinking.

SAFE YIELD SAFE YIELD

The annual quantity of water that can be taken from a source of supply over a period of years without depleting the source permanently (beyond its ability to be replenished naturally in "wet years").

SANITARY SURVEY SANITARY SURVEY

A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, treatment and distribution facilities to insure its protection from all pollution sources.

SEWAGE SEWAGE

The used water and solids from homes that flow through sewers to a wastewater treatment plant. The preferred term is WASTEWATER.

SHORT-CIRCUITING SHORT-CIRCUITING

A usually undesirable condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This results in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

STRATIFICATION (STRAT-uh-fuh-KAY-shun) STRATIFICATION

The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature.

TOPOGRAPHY TOPOGRAPHY

The arrangement of hills and valleys in a geographic area.

TRANSPIRATION (TRAN-spur-RAY-shun) TRANSPIRATION

The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.

TRIHALOMETHANES (tri-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with organic materials. The resulting compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY UNITS (TU) TURBIDITY UNITS

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

WASTEWATER WASTEWATER

The used water and solids from a community (including used water from industrial processes) that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a wastewater treatment plant. The term "sewage" usually refers to household wastes, but this word is being replaced by the term "wastewater."

WATER TABLE WATER TABLE

The upper surface of the zone of saturation of groundwater in an unconfined aquifer.

YIELD YIELD

The quantity of water (expressed as a rate of flow — GPM, GPH, GPD or total quantity per year) that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic considerations. Also see SAFE YIELD.

ZONE OF AERATION

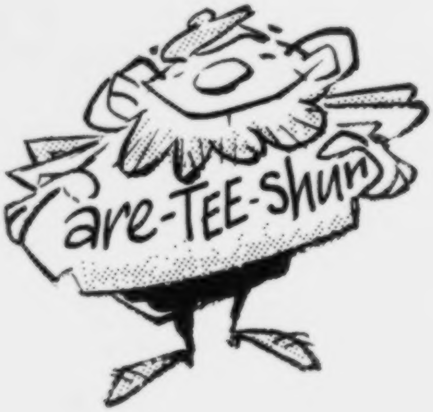
ZONE OF AERATION

The comparatively dry soil or rock located between the ground surface and the top of the water table.

ZONE OF SATURATION

ZONE OF SATURATION

The soil or rock located below the top of the groundwater table. By definition, the zone of saturation is saturated with water. Also see WATER TABLE.



CHAPTER 2. WATER SOURCES AND TREATMENT

2.0 IMPORTANCE OF WATER

For decades Americans have used water as though their supply would never fail. In recent years, drought conditions have forceably brought the need to conserve and properly budget our water resources to the minds of water supply managers. Even in the driest years, though, rain across the country enormously exceeds water use. The trouble is that the nation's water resources are poorly distributed. The Pacific Northwest has a big surplus. The agricultural states of the Southwest fight for the last salty drop of water from the Lower Colorado River. The Federal Government has spent billions of dollars building and operating facilities to divert water for use in arid and water-short areas. Contamination is a problem, too. Mineral residues from irrigation have damaged once fertile soil. *ACID RAIN*[1] is killing the fish in mountain lakes. America's drinking water has been tainted with substances as exotic as trichloroethylene (TCE) and as commonplace as highway salt. Vast underground basins of water, deposited over many years, have been seriously depleted in a matter of decades.

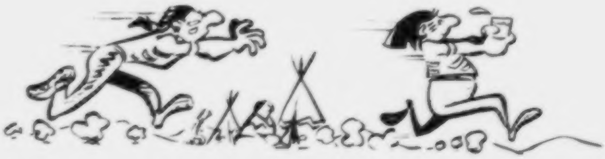
All water comes as rain or precipitation from the sky, but 92 percent of the water either evaporates immediately or runs off eventually into the oceans. One-quarter of the water that irrigates, powers and bathes America is taken from an ancient network of underground aquifers. In 1950, the United States took some 12 trillion gallons (45 billion cubic meters) of water out of the ground; by 1980 the figure had more than doubled.

The energy crisis and water shortages are linked together. As groundwater levels fall, more energy is required to pump water from deeper levels in the basin. In several areas, vast water projects use large amounts of electricity to pump water many miles along the project. As energy becomes more expensive, the users of the water wil' see the increased cost reflected in their water rates.

Water is regarded as commonplace because it is the most plentiful liquid on earth and because of our familiarity with it. All of the tissues of our bodies are bathed in it. Whatever may be the thing which we call life on earth, it requires a water environment. Our foods must be suspended or dissolved in water solutions to be carried to the different parts of the body. Also, most waste products are eliminated from the body as water-soluble substances.

Both plant life and animal life depend upon water for survival. A plant receives the greater part of its food from the soil in water solutions and manufactures the rest of its food in the presence of water.

Water is present in almost all natural objects and in almost every part of the earth that people can reach. There is water vapor in the air, and liquid water in rocks and soil. In addition to the water that wets them, clay and certain kinds of rocks contain water in chemical combination with other substances.



Water may be commonplace, but useful water is not always readily available. Even before the discovery of America, one of the common causes of war between Indian tribes was water rights. Among the first considerations of any new land development is water. Useful water is only rarely free, and it is not very abundant in many parts of the United States. There are not many places left where a person can feel safe in drinking water from a spring, stream or pond. Even the groundwater produced by wells must be tested regularly. In some areas, man's activities have made it difficult to locate a safe water supply of any sort. In certain coastal areas, for example, over-pumping from the ground has depleted the groundwater basins. As a result, the intrusion of sea water is ruining the basin for most useful purposes. Other sources of groundwater contamination include seepage from septic tank leaching systems, agricultural drainage systems, and the improper disposal of hazardous wastes in sanitary landfills and dumps. Some of man's activities clearly pose a serious threat to life on this planet.

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[1] *Acid Rain. Precipitation which has been rendered (made) acidic by airborne pollutants.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 34.

2.0A Why has it become necessary to conserve and properly budget our water resources?

2.0B How are the energy crisis and water shortage linked together?

2.0C Name three ways groundwater may become contaminated.

2.1 SOURCES OF WATER

2.10 The Hydrologic Cycle (Figure 2.1)

All water comes in the form of precipitation. Water evaporates from the ocean by the energy of the sun at an overall rate of about six feet (1.8 m) of water annually. The water which is evaporated is salt-free water, since the heavier mineral salts are left behind. This water vapor rises, is carried along by winds, and eventually condenses into clouds. When these clouds become chilled, the small particles of water collect into larger droplets which may precipitate over land or water. As the water falls in the form of rain, snow, sleet or hail, it clings to and carries with it all the dust and dirt in the air. Needless to say, the first water that falls picks up the greatest concentration of contamination. After a short period of fall, the precipitation is relatively free of pollutants. A large part of the evaporated water is carried over land masses by the winds and the droplets that fall there make up our supply of fresh water. These droplets may soak into the ground, fall as snow on the mountain tops, or collect in lakes, but in one way or another, all of the droplets seek to return to the ocean from where they came. This, in brief, is the framework of the hydrologic cycle.

2.11 Rights to the Use of Water

The rights of an individual to use water for domestic, irrigation or other purposes varies in different states. Some water rights stem from ownership of the land bordering or overlying the source, while others are acquired by a performance of certain acts required by law.

There are three basic types of water rights:

1. *RIPARIAN* — rights which are acquired with title to the land bordering a source of surface water.
2. *APPROPRIATIVE* — rights which are acquired for the beneficial use of water by following a specific legal procedure.
3. *PRESCRIPTIVE* — rights which are acquired by diverting water and putting it to use, for a period of time specified by statute, water to which other parties may or may not have prior claims. The procedure necessary to obtain prescriptive rights must conform with the conditions established by the water-rights laws of individual states.

When there is any question regarding the right to the use of water, a property owner should consult with the appropriate authority and clearly establish rights to its use.

2.12 Ocean

At some time in its history, virtually all water resided in the oceans. By evaporation, moisture is transferred from the ocean surface to the atmosphere, where winds carry the moisture-laden air over land masses. Under certain conditions, this water vapor condenses to form clouds, which release their moisture as precipitation in the form of rain, hail, sleet or snow.

When rain falls toward the earth, part of it may re-evaporate and return immediately to the atmosphere. Precipitation in excess of the amount that wets a surface or evaporates immediately is available as a potential source of water supply.

2.13 Surface Water

2.130 Direct Runoff

Surface water accumulates mainly as a result of direct runoff from precipitation (rain or snow). Precipitation that does not enter the ground through infiltration or is not returned to the atmosphere by evaporation flows over the ground surface and is classified as direct runoff. Direct runoff is water that drains off of saturated or *IMPERMEABLE*[2] surfaces, into stream channels, and then into natural or artificial storage sites (or into the ocean in coastal areas).

The amount of available surface water depends largely upon rainfall. When rainfall is limited, the supply of surface water will vary considerably between wet and dry years. In areas of scant rainfall, people build individual cisterns for the storage of rain which drains from the catchment areas of roofs. This type of water supply is used extensively in areas such as the Bermuda Islands, where groundwater is virtually non-existent and there are no streams.

Surface water supplies may be further divided into river, lake and reservoir supplies. In general, they are characterized by turbidity, suspended solids, some color, and microbiological contamination. Groundwaters, on the other hand, are characterized by higher concentrations of dissolved solids, lower levels of color, and freedom from microbiological contamination.

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[2] *Impermeable. Not able to be penetrated significantly by water.*

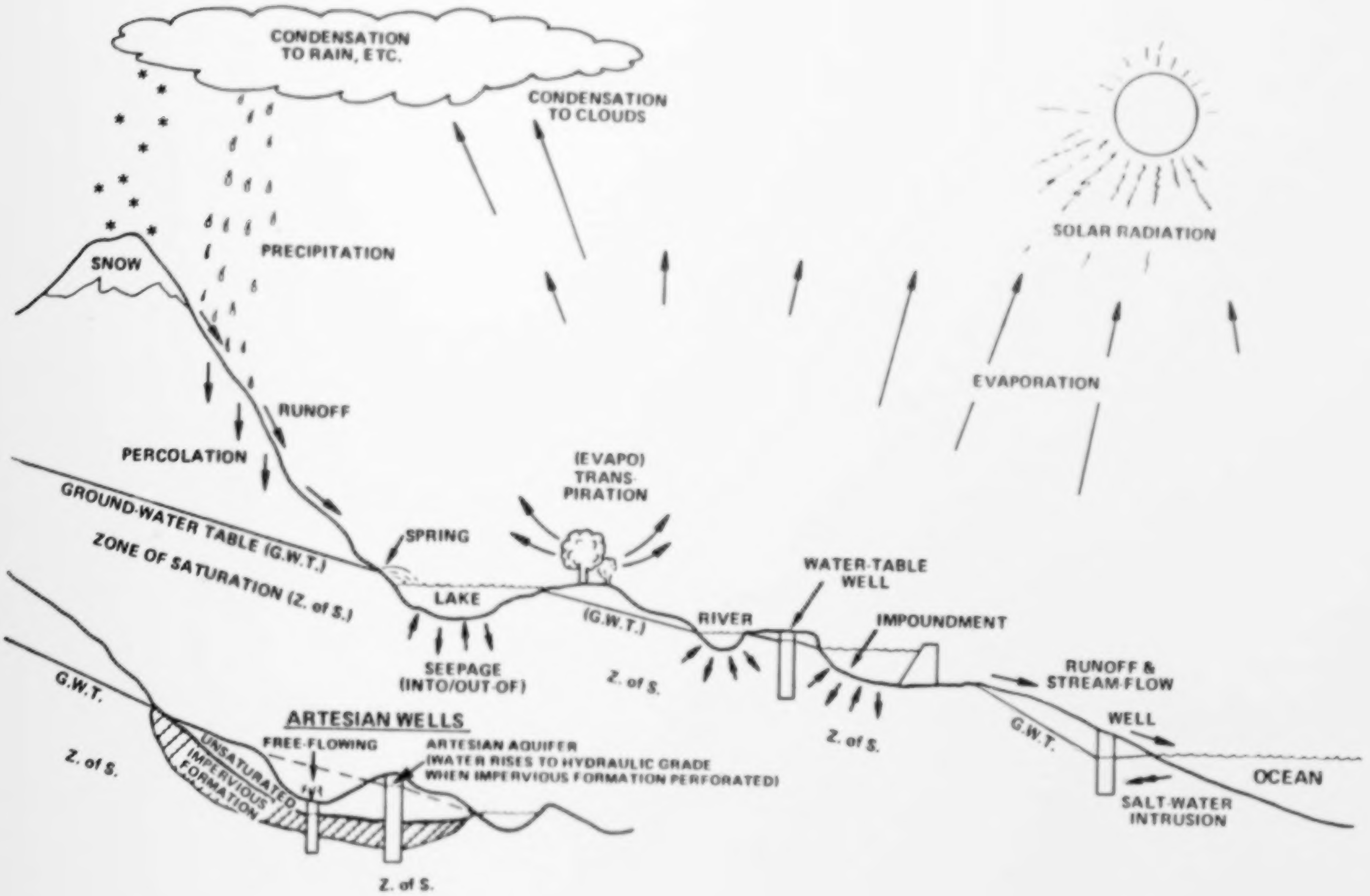
CONDENSATION TO RAIN, ETC.
CONDENSATION TO CLOUDS
SOLAR RADIATION
SNOW
PRECIPITATION
EVAPORATION
RUNOFF
PERCOLATION
(EVAPO) TRANSPIRATION
GROUND-WATER TABLE (G.W.T.)
ZONE OF SATURATION (Z. of S.)
SPRING
LAKE
WATER-TABLE WELL
RIVER
IMPOUNDMENT
(G.W.T.)
SEEPAGE (INTO/OUT-OF)
Z. of S.
RUNOFF & STREAM-FLOW
G.W.T.
ARTESIAN WELLS
FREE-FLOWING
ARTESIAN AQUIFER (WATER RISES TO HYDRAULIC GRADE WHEN IMPERVIOUS FORMATION PERFORATED)
UNSATURATED
IMPERVIOUS FORMATION
Z. of S.
Z. of S.
G.W.T.
WELL
OCEAN
SALT-WATER INTRUSION
Z. of S.

Fig. 2.1 Hydrologic cycle as related to water supply

(Source *BASIC WATER TREATMENT OPERATOR TRAINING COURSE I*, by Leonard Ainsworth, by permission of California-Nevada Section, AWWA)

2.131 Rivers and Streams

Many of the largest cities in the world depend entirely upon large rivers for their water supplies. In using a river or stream supply, one should always be concerned with upstream conditions. Some cities drink water from a stream or river into which the treated wastewater (sewage) from upstream cities has been discharged. This can present very serious problems in water treatment. Because of upstream pollution (wastewater, agricultural drainage, or industrial waste), the proper treatment of river and stream supplies is extremely important. Rivers and streams are also susceptible to scouring of the bottom, changing channels, and silting. Before the intake for a water supply is located in a river or stream, a careful study must be made of the stream bottom, its degree of scour, and the settling out of silt. Provisions must be made in the design of the intake to make sure that it can withstand the force which will act upon it during times of flood, heavy silting, ice conditions and adverse runoff conditions. Because of variations in the quality of water supplied by a river or stream, purification effectiveness must be continually checked. This is especially true if there are industries upstream from the intake which may dump undesirable wastes into the supply. Sudden pollutant loads might not be discovered unless constant monitoring of the raw water is maintained by the treatment plant operator.

2.132 Lakes and Reservoirs

The selection and use of water from any surface storage source requires considerable study and thought. When ponds, lakes, or open reservoirs are used as sources of water supply, the danger of contamination and of the consequent spread of diseases such as typhoid, hepatitis, dysentery and giardiasis exists. Clear water is not always safe water and the old saying that running water "purifies itself" to drinking water quality within a stated distance is false.

The potential for contamination of surface water makes it necessary to regard such sources of supply as unsafe for domestic use unless properly treated, including filtration and disinfection. To insure the delivery of a constant, safe drinking water to consumers also requires diligent attention to the operation and maintenance of the distribution system.

Lakes and reservoirs are subject to seasonal changes in water quality such as those brought about by *STRATIFICATION*[3] and the possible increase of organic and mineral contamination that occurs when a lake "turns over." In any body of water, the surface water will be warmed by the sun in spring and summer causing higher temperatures on the surface. Then in the fall, the cooler air temperatures cool the surface water until it reaches the same temperature as the subsurface waters. At this point, the water temperature is fairly uniform (the same) throughout the entire depth of the lake or reservoir. A breeze will start the surface water circulating and cause the lake to "turn over," thus bringing poor quality deeper water to the surface.

Lakes and reservoirs are susceptible to algal blooms, especially after fall or spring turnovers. The rapid growth of algae (blooms) will occur when the temperature is right and the water contains enough nutrients for the rapid growth of algae. In any given body of water, blooms of various types of algae can occur several times during a season depending on what algae is present and whether the conditions are right for algae growth.

Water supplies drawn from large lakes and reservoirs through multiport intake facilities (openings at several depths) are generally of good quality since the water can be drawn from a depth where algal growths are not prevalent. A large lake or reservoir also dilutes any contamination that may have been discharged into it or one of its tributaries.

Large bodies of water are generally attractive recreation areas. If the water is also used for domestic supplies, however, it must be protected from contamination. This will require proper construction and location of recreation facilities such as boat launching ramps, boat harbors, picnic and camping areas, fishing and open beach areas away from the intake area. The location and construction of wastewater collection, treatment and disposal facilities must also be carefully studied to protect domestic water supplies from contamination.

Write your answers in a notebook and then compare your answers with those on page 34.

2.1A What is the hydrologic cycle?

2.1B List the three basic types of water rights.

2.1C What are the general water quality characteristics of surface water supplies?

2.1D What are the general water quality characteristics of groundwater supplies?

2.1E What items should be considered before selecting a location and constructing a water supply intake located in a river or stream?

2.1F What water treatment processes are considered essential to reliably treat physical and bacteriologically contaminated surface waters for domestic use?

2.1G How can provisions be made to allow recreation on water supply lakes and reservoirs without endangering water quality?

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[3] *Stratification (STRAT-uh-fi-KAY-shun). The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature.*

2.14 Groundwater

2.140 Sources (refer to Fig. 2.1, page 25).

Part of the precipitation that falls infiltrates the soil. This water replenishes the soil moisture, or is used by growing plants and returned to the atmosphere by *TRANSPIRATION*[4]. Water that drains downward (percolates) below the root zone finally reaches a level at which all of the openings or voids in the earth's materials are filled with water. This zone is known as the zone of saturation. Water in the zone of saturation is referred to as groundwater. The upper surface of the zone of saturation, if not confined by impermeable material, is called the water table. When an overlying, impermeable formation confines the water in the zone of saturation under pressure, the groundwater is said to be under artesian pressure. The name "artesian" comes from the ancient province of Artesium in France where, in the days of the Romans, water flowed to the surface of the ground from a well. However, not all water from wells that penetrate artesian formations flows to ground level. For a well to be artesian, the water in the well must rise above the top of the aquifer. (An aquifer, or water-bearing formation, is an underground layer of rock or soil which permits the passage of water.)

The porous material just above the water table may contain water by capillarity in the smaller void spaces. This zone is referred to as the capillary fringe. Since the water held in the capillary fringe will not drain freely by gravity, this zone is not considered a true source of supply.

Because of the irregularities in underground deposits or layers and in surface *TOPOGRAPHY*[5], the water table occasionally intersects (meets) the surface of the ground at a spring or in the bed of a stream, lake or the ocean. As a result, groundwater moves to these locations as seepage out of the aquifer (groundwater reservoir). Thus, groundwater is continually moving within aquifers even though the movement may be very slow (see Figure 2.1). The water table (artesian pressure surface) thus may slope from areas of recharge to lower areas of discharge. The pressure difference represented by these slopes causes the flow of groundwater within the aquifer. Seasonal variations in the supply of water to the underground reservoir cause considerable changes in the elevation and slope of the water table and the artesian pressure level.

2.141 Wells

A well that penetrates the water table can be used to extract water from the groundwater basin (see Figure 2.1). The removal of water by pumping will naturally cause a lowering of the water table near the well. If pumping continues at a rate that exceeds the rate of replacement by the water-bearing formations, the "sustained yield" of the well or group of wells has been exceeded. The "safe yield" will be exceeded if wells extract water from an aquifer over a period of time at a rate that will deplete the aquifer and bring about other undesired results (such as sea water intrusion and land subsidence). This situation is a poor practice, but occurs quite frequently in many areas of the U.S.

2.142 Springs

Groundwater that flows naturally from the ground is called a spring. Depending upon whether the discharge is from a water table or an artesian aquifer, springs may flow by gravity or by artesian pressure. The flow from a spring may vary considerably; when the water table or artesian pressure fluctuates, so does the flow from the spring.

2.15 Reclaimed Water

The use of treated wastewater as a source of water for non-food crop irrigation is an established practice in many regions of the world. The type of crop which can be safely irrigated depends somewhat on the quality of wastewater and method of irrigation. At the present time, more than 20,000 acres (8,000 hectares) of agricultural lands in California are irrigated, all or in part, with reclaimed water. Two of the largest operations are at Bakersfield and at Fresno, California. The City of Bakersfield has used wastewater effluent for irrigation since 1912. At the present time, approximately 2,400 acres (1,000 hectares) of alfalfa, cotton, barley, sugar beets and pasture are irrigated. Fresno irrigates 3,500 acres (1,400 hectares) of the same type of crops. These two operations use almost 30,000 acre-feet (37 million cubic meters) of reclaimed water per year. Almost 90 percent of the 2,000,000 acre-feet (2.5 billion cubic meters) of reclaimed wastewater in California is used for crop irrigation.

Other uses for reclaimed wastewater include:

1. Greenbelt (parks) areas,
2. Golf course irrigation,
3. Landscape irrigation,
4. Industrial reuse,
5. Groundwater recharge,
6. Landscape impoundments, and
7. Wetlands — marsh enhancement.

Reclaimed water can be used safely for any of these purposes, with the possible exception of groundwater recharge. Health experts have serious questions regarding organic compounds that are present in wastewater and about our ability to reduce them to safe levels. These doubts increase further when we realize that a large number of new and potentially toxic chemicals are developed each year. Laboratories are unable to adequately detect all of these chemicals without expensive monitoring programs. To protect groundwater resources regulations require that "reclaimed water used for groundwater recharge of domestic water supply aquifers by surface spreading shall be at all times of a quality that fully protects public health." Proposed groundwater recharge projects must be investigated on an individual basis where the use of reclaimed water involves a potential risk to public health.

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[4] *Transpiration (TRAN-spur-RAY-shun). The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.*

[5] *Topography. The arrangement of hills and valleys in a geographic area.*

Treatment of reclaimed water should be appropriate for the intended use. The greater the potential exposure to the public, the more extensive the treatment needs to be. Regulations often specify not only the degree of treatment for the useage of water, but also the reliability features that must be incorporated into the treatment processes to assure a continuous high degree of finished water quality. Studies indicate that the average reclamation plant does not achieve the quality of treatment expected on a continuous basis. This is of concern to the water supplier and also the regulatory agencies that are charged with the responsibility of assuring that the health of the public is protected.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 34.

2.1H What causes the flow of groundwater within an aquifer?

2.1I How can the "safe yield" of an aquifer be exceeded?

2.1J List some of the possible uses of reclaimed wastewater.

2.1K How much treatment should reclaimed water receive before use?

2.2 SELECTION OF A WATER SOURCE

2.20 Sanitary Survey[6]

The importance of detailed sanitary surveys of water supply sources cannot be overemphasized. With a new supply, the sanitary survey should be made during the collection of initial engineering data covering the development of a given source and its capacity to meet existing and future needs. The sanitary survey should include the location of all potential and existing health hazards and the determination of their present and future importance. Persons trained in public health engineering and the *EPIDEMIOLOGY*[7] of water-borne diseases should conduct the sanitary survey. In the case of an existing supply, sanitary surveys should be made frequently enough to control health hazards and to maintain high water quality.

The information furnished by a sanitary survey is essential to evaluating the bacteriological and chemical water quality data. The following outline lists the essential factors which should be investigated or considered in a sanitary survey. These items are essential to (1) identify potential hazards, (2) determine factors which affect water quality, and (3) select treatment requirements. Not all of the items are important to any one supply and, in some cases, items not in the list could be found to be significant during the field investigation.

GROUNDWATER SUPPLIES:

a. Character of local geology; slope (topography) of ground surface.

b. Nature of soil and underlying porous material; whether clay, sand, gravel, rock (especially porous limestone); coarseness of sand or gravel; thickness of water-bearing stratum; depth of water table; location and *GEOLOGICAL LOG*[8] of nearby wells.

c. Slope of water table, preferably as determined from observation wells or as indicated by slope of the ground surface.

d. Extent of the drainage area likely to contribute water to the supply.

e. Nature, distance, and direction of local sources of pollution.

f. Possibility of surface-drainage water entering the supply and of wells becoming flooded.

g. Methods used for protecting the supply against contamination from wastewater collection and treatment facilities and industrial waste disposal sites.

h. Well construction: materials, diameter, depth of casing and concrete collar; depth to well screens or perforations; length of well screens or perforations.

i. Protection of well head at the top and on the sides.

j. Pumping station construction (floors, drains); capacity of pumps; storage or direct to distribution system.

k. Drawdown when pumps are in operation; recovery rate when pumps are off.

l. Presence of an unsafe supply nearby, and the possibility of *CROSS-CONNECTIONS*[9] causing a danger to the public health.

m. Disinfection: equipment, supervision, test kits, or other types of laboratory control.

SURFACE WATER SUPPLIES:

a. Nature of surface geology, character of soils and rocks.

b. Character of vegetation; forests; cultivated and irrigated land.

c. Population and wastewater collection, treatment and disposal on the watershed.

d. Methods of wastewater disposal, whether by diversion from watershed or by reclamation treatment.

e. Closeness of sources of fecal pollution (especially birds) to intake of water supply.

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[6] *Sanitary Survey. A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, and treatment and distribution facilities to insure its protection from all pollution sources.*

[7] *Epidemiology (EP-uh-DEE-me-ALL-O-gee). A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.*

[8] *Geological Log. A detailed description of all underground features discovered during the drilling of a well (depth, thickness and type of formations).*

[9] *Cross-Connection. A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.*

f. Proximity and character of sources of industrial wastes, oil field brines, acid waters from mines, and agricultural drain waters.

g. Adequacy of supply as to quantity (safe yield).

h For lake or reservoir supplies: wind direction and velocity data; drift of pollution; and algae growth potential.

i. Character and quality of raw water: typical coliform counts (MPN or membrane filter), algae, turbidity, color, and objectionable mineral constituents.

j. Normal period of *DETENTION TIME*[10].

k. Probable minimum time required for water to flow from sources of pollution to reservoir and through the reservoir to the intake tower.

l. The possible currents of water within the reservoir (induced by wind or reservoir discharge) which could cause *SHORT-CIRCUITING*[11] to occur.

m. Protective measures in connection with the use of the watershed to control fishing, boating, landing of airplanes, swimming, wading, ice cutting, and permitting animals on shore-line areas.

n. Efficiency and constancy of policing activities on the watershed and around the lake.

o. Treatment of water: kind and adequacy of equipment; duplication of parts for reliable treatment; effectiveness of treatment; numbers and competency of supervising and operating personnel; contact period after disinfection; free chlorine residuals and monitoring of the water supply both during treatment and following treatment.

p. Pumping facilities: pump station design, pump capacity and standby unit(s).

q. Presence of an unsafe supply nearby, and the possibility of cross-connections causing a danger to the public health.

2.21 Precipitation

Precipitation in the form of rain, snow, hail, or sleet contains very few impurities. (However, there are exceptions such as acid rain and dust from Dust Bowl areas.) Trace amounts of mineral matter, gases, and other substances may be picked up by precipitation as it forms and falls through the earth's atmosphere. Precipitation, however, has virtually no microbiological content.

Once precipitation reaches the earth's surface, many opportunities are presented for the introduction of mineral and organic substances, microorganisms, and other forms of contamination. When water runs over or through the ground surface it may pick up particles of soil. This is noticeable in the water as cloudiness or turbidity. This water also picks up particles or organic matter and microorganisms. As surface water seeps downward into the soil and through the underlying material to the water table, most of the suspended particles are filtered out. This natural filtration may be partially effective in removing microorganisms and other particulate materials; however, the chemical characteristics of the water usually change considerably when it comes in contact with underground mineral deposits.

The widespread use of synthetically-produced chemical compounds, especially pesticides, has raised concern for their potential to contaminate water. Many of these materials are known to be toxic (poisonous), some cause cancer, and others have certain undesirable characteristics even when present in a relatively small concentration.

Agents which alter the quality of water as it moves over or below the surface of the earth may be classified under four major headings:

A. *PHYSICAL* — Physical characteristics relate to the sensory qualities of water for domestic use; for example, the water's observed color, turbidity, temperature, taste and odor.

B. *CHEMICAL* — Chemical differences between waters include mineral content and the presence or absence of constituents such as fluoride, sulfide, and acids. The comparative performance of hard and soft waters in laundering is one visible effect.

C. *BIOLOGICAL* — The presence of organisms (virus, bacteria, algae, mosquito larvae), alive or dead, and their metabolic products determine the biological character of water. These may also be significant in modifying the physical and chemical characteristics of water.

D. *RADIOLOGICAL* — Radiological factors must be considered because there is a possibility that the water may have come in contact with radioactive substances.

Consequently, in the development of water supply systems, it is necessary to examine carefully all the factors which might adversely affect the water supply.

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[10] *Detention Time. In storage reservoirs, detention time is the length of time entering water is held before being drafted for use (several weeks to years, several months being typical).*

[11] *Short-Circuiting. A usually undesirable condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This results in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 34 and 35.

2.2A What is the purpose of a sanitary survey?

2.2B How frequently should a sanitary survey be conducted for an existing water supply?

2.2C When conducting a sanitary survey, what protective measures should be investigated regarding use of the watershed?

2.2D List the common physical characteristics of water.

2.22 Physical Characteristics

To be suitable for human use, water should be free from all impurities which are offensive to the senses of sight, taste, and smell. The physical characteristics which might be offensive include turbidity, color, taste, odor and temperature.

TURBIDITY: The presence of suspended material in water causes cloudiness which is known as turbidity. Clay, silt, finely divided organic material, plankton, and other inorganic materials give water this appearance. Turbidities in excess of 5 turbidity units are easily visible in a glass of water, and this level is usually objectionable for aesthetic reasons. Turbidity's major danger in drinking water is that it can harbor bacteria as well as exert a high demand on chlorine. Water that has been filtered to remove the turbidity should have considerably less than one turbidity unit. Good treatment plants consistently obtain finished water turbidity levels of from 0.05 to 0.3 units.

COLOR: Dissolved organic material from decaying vegetation and certain inorganic matter cause color in water. Occasionally, excessive blooms of algae or the growth of other aquatic microorganisms may also impart color. Iron and manganese may be the cause of consumer complaints (red or black water). While the color itself is not objectionable from the standpoint of health, its presence is aesthetically objectionable and suggests that the water needs better treatment. In some instances however, a color in the water indicates more than an aesthetic problem. For example, an amber color in the water could indicate the presence of humic substances which could later be formed into trihalomethanes or it could indicate acid waters from mine drainage.

TEMPERATURE: The most desirable drinking waters are consistently cool and do not have temperature fluctuations of more than a few degrees. Groundwater and surface water from mountainous areas generally meet these requirements. Most individuals find that water having a temperature between 50° and 60°F (10° and 15°C) is most pleasing while water over 86°F (30°C) is not acceptable. The temperature of groundwaters varies with the depth of the aquifer. Water from very deep wells (more than 1000 ft or 300 m) may be quite warm. Temperature also affects sensory perception of tastes and odors.

TASTES: Each area's natural waters have a distinctive taste related to the dissolved mineral characteristics of local geology. Occasionally, algal growths also impact a distinctive taste. However, taste is rarely measured since most water treatment plants cannot alter a water's mineral characteristics.

ODORS: Growths of algae in a water supply can give the water an unpleasant odor. Some groundwaters may contain hydrogen sulfide which will produce a disagreeable rotten egg odor.

2.23 Chemical Characteristics

The nature of the materials that form the earth's crust affects not only the quantity of water that may be recovered, but also its chemical makeup. As surface water infiltrates and percolates downward to the water table, it dissolves some of the minerals contained in soils and rocks. Groundwater, therefore, sometimes contains more dissolved minerals than surface water. The use and disposal of chemicals by society can also affect water quality.

Chemical analysis of a domestic water supply, is broken down into three areas:

1. Inorganic chemicals; which include the toxic (poisonous) metals — arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver; and the nonmetals — fluoride and nitrate.
2. Organic chemicals which include the pesticides (chlorinated hydrocarbons) — Endrin, Lindane, Methoxychlor and Toxaphene, and the Chlorophenoxys; and
3. The general mineral constituents which include alkalinity, calcium, chloride, copper, foaming agents (MBAS), iron, magnesium, manganese, pH, sodium, sulfate, zinc, specific conductance, total dissolved solids, and hardness (calcium and magnesium).

Upper limits for the concentrations of the chemicals listed in this section have been established by the Safe Drinking Water Act. For a summary of the Drinking Water Regulations established by the Act, see the poster included with this manual. Chapter 22, "Drinking Water Regulations," *WATER TREATMENT PLANT OPERATION*, Volume II, contains a detailed discussion of the Safe Drinking Water Act.

2.24 Biological Factors

Water for domestic purposes must be made free from disease-producing (pathogenic) organisms. These organisms include bacteria, protozoa, spores, viruses, cysts, and helminths (parasitic worms).

Many organisms which cause disease in man originate with the fecal discharges of infected individuals. To monitor and control the activities of human disease-carriers is seldom practical. For this reason, it is necessary to take precautions to prevent contamination of a normally safe water source or to institute treatment methods which will produce a safe water.

Unfortunately, the specific disease-producing organisms present in water are not easily isolated and identified. The techniques for comprehensive bacteriological examination are complex and time-consuming. Therefore, it has been necessary to develop tests which indicate the relative degree of contamination in terms of an easily defined quality. The most widely used test involves estimation of the number of bacteria of the coliform group, which are always present in fecal wastes and vastly outnumber disease-producing organisms. Coliform bacteria normally inhabit the intestinal tract of man, but are also found in most animals and birds, as well as in the soil. The Drinking Water Standards in the Safe Drinking Water Act have established upper limits for the concentration of coliform bacteria in a series of water samples (roughly, no more than one organism per 100 mL of sample water).

2.25 Radiological Factors

The development and use of atomic energy as a power source and the mining of radioactive materials have made it necessary to examine the safe limits of exposure for humans. Such limits include concentrations of radioactive material taken into the body in drinking water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 35.

2.2E What causes turbidity in water?

2.2F Chemical analysis of a domestic water supply measures what three general types of chemical concentrations?

2.2G Why are coliform bacteria used to measure the bacteriological quality of water?

2.2H Why must upper limit concentrations of radioactive materials in drinking water be established?

2.3 THE SAFE DRINKING WATER ACT

On December 16, 1974, the Safe Drinking Water Act (SDWA) was signed into law. The Act set up a cooperative program among local, state and federal agencies. As directed by the Act the Environmental Protection Agency developed primary drinking water regulations designed to insure safe drinking water for consumers.

A study of the health effects of various contaminants in water was begun soon after the SDWA was signed into law. The regulations were developed in two stages so that the findings of this investigation and other studies could be incorporated into the regulations. The interim regulations became effective June 24, 1977, and they were followed by revised regulations.

All public water systems must comply with the regulations. This includes all public or privately owned systems that:

1. Have at least 15 service connections which are used at least 60 days out of the year, or
2. Serve an average of at least 25 people at least 60 days out of the year.

The regulations apply to two kinds of public water systems: (1) community water systems, and (2) non-community water systems.

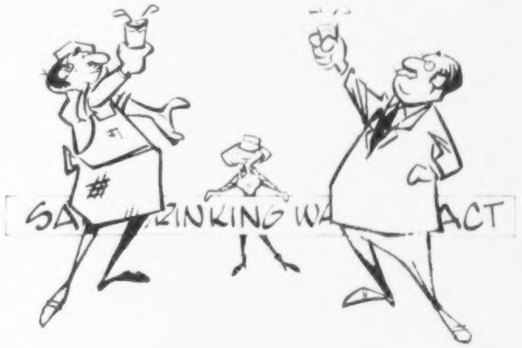
A community water system is defined as follows:

1. Has at least 15 service connections used by all-year residents, or
2. Services at least 25 all-year residents.

A non-community water system is defined as follows:

1. Has at least 15 service connections used by travelers or intermittent users at least 60 days a year, or
2. Services a daily average of at least 25 people at least 60 days a year.

Water has many important uses and each requires certain specific levels of water quality. The major concern of the operators of water treatment plants and water supply systems is to produce and deliver to consumers water meeting the standards established by the Safe Drinking Water Act. The water should be acceptable to domestic and commercial water users and many industries. Some industries, such as food and drug processors and the electronics industry, require higher quality water. Many industries will locate where the local water supply meets their specific needs while other industries may have their own water treatment facilities to produce water suitable for their needs.



The maximum contaminant levels (MCLs) and also the sampling and testing requirements established by the Safe Drinking Water Act are summarized on the poster included with this manual. For additional information on the Safe Drinking Water Act, see *WATER TREATMENT PLANT OPERATION*, Volume 11, Chapter 22, "Drinking Water Regulations." The new Safe Drinking Water Act Amendment were signed into law on June 19, 1986.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 35.

2.3A The Safe Drinking Water Act (SDWA) set up a cooperative program among which agencies?

2.3B What were the two stages under which the regulations under the SDWA were developed?

2.3C Community and non-community water systems are different in what respect?

2.3D Which industries require extremely high quality water?

2.4 WATER TREATMENT

In the operation of water treatment plants, three basic objectives are controlling:

1. Production of a safe drinking water,
2. Production of an aesthetically pleasing drinking water, and
3. Production of drinking water at a reasonable cost with respect to capital and also operation and maintenance costs.

From a public health perspective, production of a safe drinking water, one that is free of harmful bacteria and toxic materials, is the first priority. But, it is also important to produce a high quality water which appeals to the consumer. Generally, this means that the water must be clear (free of turbidity), colorless, and free of objectionable tastes and odors. Consumers also show a preference for water supplies that are nonstaining (plumbing fixtures and washing clothes), noncorrosive to plumbing fixtures and piping, and one that does not leave scale deposits or spot glassware.

Consumer sensitivity to the environment (air quality, water quality, noise) has significantly increased in recent years. With regard to water quality, consumer demands have never been greater. In some instances, consumers have substituted bottled water to meet specific needs, namely, for drinking water and cooking purposes.

Design engineers select water treatment processes on the basis of the type of water source, source water quality, and desired finished water quality established by drinking water regulations and consumer desires. Table 2.1 is a summary of typical water treatment processes and plants depending on the source and quality of the raw water.

Operators of water treatment facilities must be very conscientious in order to produce a high quality finished water. Also they must realize that water can degrade in the distribution or delivery system. The remainder of this manual contains chapters written by operators on how to produce and deliver high quality drinking water to consumers.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 35.

2.4A What is the first priority for operating a water treatment plant?

2.4B What type of water is appealing to consumers?

TABLE 2.1 SOURCES AND TREATMENT OF WATER

GROUNDWATER

WATER QUALITY PROBLEM	*TREATMENT*[a]
1. Coliforms or Microbiological Contamination	1. Disinfection (Chlorination)
2. Sulfide Odors (Rotten Egg)	2a. Aeration 2b. Oxidation (Chlorination) 2c. Desulfuration (Sulfur Dioxide)
3. Excessive Hardness (Calcium and Magnesium)	3a. Ion Exchange Softening 3b. Lime (& Soda) Softening
4. Iron and/or Manganese	4a. Sequestration (Polyphosphates) 4b. Removal by Special Ion Exchange 4c. Permanganate and Greensand 4d. Oxidation by Aeration* 4e. Oxidation with Chlorine* 4f. Oxidation with Permanganate* *Filtration Must Follow Oxidation
5. Dissolved Minerals (High Total Dissolved Solids)	5a. Ion Exchange 5b. Reverse Osmosis
6. Corrosivity (Low pH)	6a. pH Adjustment with Chemicals 6b. Carbon Dioxide Stripping by Aeration 6c. Corrosion Inhibitor Addition (Zinc Phosphate, Silicate)
7. Preventive Treatment (Fluoridation)	7. Add Fluoride Chemicals
8. Sand	8. Sand Separators
9. Nitrate	9. Anion Exchange

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[a] For details on the treatment processes, refer to the appropriate chapters in these manuals.

TABLE 2.1 SOURCES AND TREATMENT OF WATER (Continued)

SURFACE WATER

WATER QUALITY PROBLEM	*TREATMENT*[a]
1. Coliforms or Microbiological Contamination	1a. Disinfection (Chlorination) 1b. Disinfection (Other Oxidants — Ozone, Chlorine Dioxide, Chloramination) 1c. Coagulation, Flocculation, Sedimentation, Filtration and Disinfection
2. Turbidity, Color	2. Coagulation, Flocculation, Sedimentation and Filtration
3. Odors (Organic Materials)	3a. Clarification (Coagulation, Flocculation, Sedimentation and Filtration) 3b. Oxidation (Chlorination or Permanganate) 3c. Special Oxidation (Chlorine Dioxide) 3d. Adsorption (Granular Activated Carbon)
4. Iron and/or Manganese	4a. Sequestration (Polyphosphates) 4b. Removal by Special Ion Exchange 4c. Permanganate and Greensand 4d. Oxidation by Aeration* 4e. Oxidation with Chlorine* 4f. Oxidation with Permanganate* *Filtration Must Follow Oxidation
5. Excessive Hardness (Calcium and Magnesium)	5a. Ion Exchange Softening 5b. Lime (& Soda) Softening
6. Dissolved Minerals (High Total Dissolved Solids)	6a. Ion Exchange 6b. Reverse Osmosis
7. Corrosivity (Low pH)	7a. pH Adjustment with Chemicals 7b. Corrosion Inhibitor Addition (Zinc Phosphate, Silicate)
8. Preventive Treatment	
a. Fluoridation	8a. Add Fluoride Chemicals
b. Trihalomethanes (THMs)	8b. (1) Do not Prechlorinate. Disinfect with Ozone, Chlorine Dioxide, or Chloramination (2) Remove THM Precursors (3) Remove THMs after They Are Formed

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[a] For details on the treatment processes, refer to the appropriate chapters in these manuals.

2.5 ARITHMETIC ASSIGNMENT

A good way to learn how to solve arithmetic problems is to work on them a little bit at a time. In this operator training manual we are going to make a short arithmetic assignment at the end of every chapter. If you will work this assignment at the end of every chapter, you can easily learn how to solve waterworks arithmetic problems.

Turn to the Appendix at the back of this manual and read the following sections:

1. OBJECTIVES,
2. A.O HOW TO STUDY THIS APPENDIX, and
3. A.1 BASIC ARITHMETIC.

Solve all of the problems in Sections A.10, Addition; A.11, Subtraction; A.12, Multiplication; A.13, Division; A.14, Multiplication and Division; and A.15, Actual Problems; on an electronic pocket calculator.

2.6 ADDITIONAL READING

1. AWWA. *INTRODUCTION TO WATER SOURCES AND TRANSMISSION*, Volume I, Module 1, "Sources and Characteristics."
2. *NEW YORK MANUAL*, Chapter 2, "Water Sources and Water Uses."
3. *TEXAS MANUAL*, Chapter 2, "Groundwater Supplies;" Chapter 3, "Surface Water Supplies;" and Chapter 4, "Raw Water Quality Management."
4. *WATER: A PRIMER*, by Luna B. Leopold. Available from W.H. Freeman and Company, San Francisco, CA 94104. Price, $20.25

DISCUSSION AND REVIEW QUESTIONS

Chapter 2. WATER SOURCES AND TREATMENT

DO NOT USE IBM ANSWER SHEET. Please write your answers to these questions in your notebook before continuing with the Objective Test on page 35. The purpose of these questions is to indicate to you how well you understand the material in this chapter.

1. What has been the impact of drought conditions on the managers of water supplies?
2. Why has the quality of many water supplies deteriorated?
3. How does the hydrologic cycle work?
4. What are water rights?
5. What are the differences between the water quality characteristics of groundwater and surface water supplies?
6. Lakes turn over under what conditions?
7. Algae blooms in reservoirs occur under what general conditions?
8. How can a lake used for a water supply also be used for recreation without endangering water quality?
9. The elevation and slope of water tables and artesian pressure levels can change due to what factors?
10. Who should conduct a sanitary survey? Why?

SUGGESTED ANSWERS

Chapter 2. WATER SOURCES AND TREATMENT

Answers to questions on page 24.

2.0A Drought conditions have forced water supply managers to recognize the need to conserve and properly budget our water resources. Other reasons include the increasing costs of energy and chemicals.

2.0B The energy crisis and water shortage are linked together because (1) with falling groundwater levels energy is required to pump from deeper levels, and (2) water projects that use large amounts of electricity to pump water over long distances are requiring water users to pay increased water rates to cover higher energy costs.

2.0C Groundwater becomes contaminated from (1) sea water intrusion, (2) seepage from septic tank leaching systems, (3) agricultural drainage systems, and (4) seepage from improper disposal of hazardous wastes.

Answers to questions on page 26.

2.1A The hydrologic cycle is the cycle or path water follows from evaporation from oceans, to formation of clouds, to precipitation, to runoff, to evaporation and transpiration back to the atmosphere, and eventually back to the ocean.

2.1B The three basic types of water rights are:
1. Riparian,
2. Appropriative, and
3. Prescriptive.

2.1C In general, surface water supplies are characterized by suspended solids, turbidity, some color, and microbiological contamination.

2.1D In general, groundwater supplies are characterized by higher concentrations of dissolved solids, and low color, but freedom from bacterial contamination.

2.1E Before selecting a location and constructing a water supply intake in a river or stream, careful consideration must be given to (1) the stream bottom, its degree of scour, and the settling out of silt, and (2) design of the intake to make sure that it can withstand the forces which will act upon it during times of flood, heavy silting, ice conditions, and adverse runoff conditions.

2.1F Filtration and disinfection are considered essential water treatment processes to reliably treat physically and bacteriologically contaminated surface waters for domestic use.

2.1G Lakes and reservoirs used for domestic water supplies can be protected from contamination by (1) proper construction and location of recreation facilities; and (2) careful evaluation of adverse effects of the construction of wastewater collection, treatment and disposal facilities near the reservoir or its tributaries.

Answers to questions on page 28.

2.1H Groundwater flows within an aquifer because of the pressure differences between the areas of recharge and discharge.

2.1I The "safe yield" of an aquifer can be exceeded if wells extract water from an aquifer over a period of time at a rate such that the aquifer will become depleted or bring about other undesired results, such as sea water intrusion and land subsidence.

2.1J Possible uses of reclaimed wastewater include: (1) crop irrigation, (2) greenbelt irrigation, (3) golf course irrigation, (4) landscape irrigation, (5) industrial reuse, (6) groundwater recharge, (7) landscape impoundments, and (8) wetlands — marsh enhancement.

2.1K Reclaimed water should receive treatment that is appropriate for the intended use of the water.

Answers to questions on page 30.

2.2A The purpose of a sanitary survey is to detect all health hazards and to evalute their present and future importance.

2.2B For an existing water supply, a sanitary survey should be made frequently enough to control all health hazards and to maintain good sanitary water quality.

2.2C When conducting a sanitary survey, protective measures that should be investigated include control of sources of waste discharges (municipal wastewater treatment plants, sources of fecal pollution, industrial wastes, oil field brines, acid waters from mines, and agricultural drain waters), fishing, boating, landing of airplanes, swimming, wading, ice cutting, and permitting animals on shore-line areas.

2.2D The common physical characteristics of water are observable color, turbidity, temperature, taste, and odor.

Answers to questions on page 31.

2.2E Turbidity in water is caused by the presence of suspended material such as clay, silt, finely divided organic material, plankton, and other inorganic material.

2.2F The three general types of chemicals measured by a chemical analysis of domestic water supplies are inorganic, organic and general mineral concentrations.

2.2G Coliforms are used to measure the bacteriological quality of drinking water because the test indicates the fecal contamination where specific disease-producing organisms are not easily isolated and identified.

2.2H The development and use of atomic energy as a power source and the mining of radioactive materials have made it necessary to establish upper limit concentrations for drinking water.

Answers to questions on page 32.

2.3A The Safe Drinking Water Act (SDWA) set up a cooperative program among local, state and federal agencies.

2.3B The regulations under the SDWA were developed in two stages so that findings of investigations and other studies could be incorporated into the regulations. The interim regulations became effective June 24, 1977, and they were followed by revised regulations.

2.3C Community water systems serve all-year residents while non-community systems serve consumers at least 60 days a year.

2.3D Food and drug processors and also electronic industries require extremely high quality water.

Answers to questions on page 32.

2.4A The first priority for operating a water treatment plant is the production of a safe drinking water, one that is free of harmful bacteria and toxic materials.

2.4B Water that appeals to consumers must be clear (free of turbidity), colorless, and free of objectionable tastes and odors. Consumers also show a preference for water supplies that are nonstaining (plumbing fixtures and washing clothes), noncorrosive to plumbing fixtures and piping, and one that does not leave scale deposits or spot glassware.

OBJECTIVE TEST

Chapter 2. WATER SOURCES AND TREATMENT

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True — False

1. Running water usually purifies itself to drinking water quality within a reasonable distance.

   1. True
   2. False

2. Clear water is usually safe to drink.

   1. True
   2. False

3. Color in water is objectionable from the standpoint of both health and aesthetics.

   1. True
   2. False

4. The energy crisis and water shortages are linked together.

   1. True
   2. False

5. The specific disease-producing organisms present in water are easily identified.

   1. True
   2. False

6. Animal life and plant life both depend on water for survival.

   1. True
   2. False

7. Precipitation is high in bacterial count.

   1. True
   2. False

8. Acid rain is formed by the evaporation of acid waters from mine drainage.

   1. True
   2. False

9. Laboratories can easily detect in water samples most of the new chemicals that are developed each year.

   1. True
   2. False

10. Large cities may obtain their raw water supply from a stream or river into which the treated wastewater from an upstream city has been discharged.
    1. True
    2. False

Multiple Choice

11. For purposes of discussion, surface water supplies may be divided into which of the following classes?
    1. Artesian aquifers
    2. Lakes
    3. Reservoirs
    4. Rivers
    5. Wells

12. The basic types of water rights are called
    1. Acquired.
    2. Appropriative.
    3. Beneficial.
    4. Prescriptive.
    5. Riparian.

13. Sources of contamination of water supplies include
    1. Acid rain.
    2. Industrial waste discharges.
    3. Intrusion of sea water into groundwater basins.
    4. Mineral residues from irrigation.
    5. Salts from de-icing highways.

14. Sources of groundwater contamination include
    1. Agricultural drainage.
    2. Sea water intrusion.
    3. Seepage from septic tank leaching systems.
    4. Seepage from improper disposal of hazardous wastes.
    5. Surface runoff into wells.

15. When conducting a sanitary survey, which of the following items would pertain to a water supply in a lake?
    1. Adequacy of supply as to quantity
    2. Algae growth potential
    3. Normal period of detention
    4. Protective measures in connection with watershed use
    5. Wind direction

16. When conducting a sanitary survey, which of the following items would pertain to a groundwater supply?
    1. Distance to sources of pollution
    2. Nature of soil
    3. Slope of ground surface
    4. Slope of water table
    5. Well construction

17. Diseases that may be spread through a water supply include
    1. Chicken pox.
    2. Dysentery.
    3. Giardiasis.
    4. Small pox.
    5. Typhoid fever.

18. Typical uses of reclaimed water include
    1. Crop irrigation.
    2. Drinking.
    3. Industrial reuse.
    4. Landscape impoundments.
    5. Landscape irrigation.

19. Turbidity in water results from the presence of
    1. Finely divided organic material.
    2. Hardness.
    3. pH.
    4. Plankton.
    5. Suspended material.

20. Most individuals find that water having a temperature between _______ is most palatable.
    1. 30° to 40° F.
    2. 40° to 50° F.
    3. 50° to 60° F.
    4. 60° to 70° F.
    5. 70° to 80° F.

21. Activities requiring control measures for water quality protection in watersheds that serve as the source of a water supply include control of
    1. Disposal of brines.
    2. Ice cutting.
    3. Lake and stream fishing.
    4. Sanitary landfills.
    5. Swimming.

22. Which types of substances may alter the quality of water as it moves over or below the surface of the earth?
    1. Biological
    2. Chemical
    3. Epidemiological
    4. Physical
    5. Radiological

23. Sources of odors in drinking water include
    1. Dissolved oxygen.
    2. Growths of algae.
    3. Hydrogen sulfide.
    4. pH.
    5. Temperature.

24. Lakes and reservoirs are susceptible to algal blooms when
    1. Maximum cloud cover occurs.
    2. Optimum level of hardness is present.
    3. Sufficient nutrients are available.
    4. Temperature is suitable.
    5. Water is completely stratified.

25. The process by which water vapor is released to the atmosphere by living plants is called
    1. Evaporation.
    2. Hydrologic cycle.
    3. Infiltration.
    4. Precipitation.
    5. Transpiration.

26. Water quality characteristics of surface water supplies are described in terms of
    1. Color.
    2. Feeling.
    3. Touch.
    4. Turbidity.
    5. Vibration.

27. The basic objectives in the operation of a water treatment plant include
    1. Keeping management happy.
    2. Keeping regulatory agencies happy.
    3. Production of a safe drinking water.
    4. Production of an aesthetically pleasing drinking water.
    5. Production of drinking water at a reasonable cost.

28. A public water system according to the Safe Drinking Water Act (SDWA) includes all public or privately owned systems that
    1. Are owned and operated by a public agency.
    2. Have at least 15 service connections which are used at least 60 days out of the year.
    3. Have at least 25 service connections which are used at least 60 days out of the year.
    4. Service an average of at least 15 people at least 60 days out of the year.
    5. Serve an average of at least 25 people at least 60 days out of the year.

29. Determine the chlorinator setting in pounds per day if

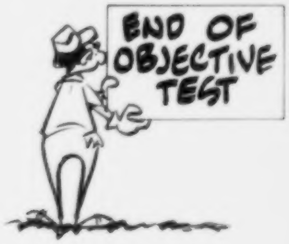
Chlorinator Feed Rate, lbs/day = (2 MGD)(3 mg/*L*)(8.34 lbs/gal)

    1. 6 lbs/day
    2. 16 lbs/day
    3. 24 lbs/day
    4. 36 lbs/day
    5. 50 lbs/day

30. Estimate the chlorine dose to a drinking water in mg/*L* if

$$\text{Chlorine Dose, mg}/L = \frac{14 \text{ lbs/day}}{(0.933 \text{ MGD})(8.34 \text{ lbs/gal})}$$

    1. 0.3 mg/*L*
    2. 1.8 mg/*L*
    3. 2.5 mg/*L*
    4. 3.3 mg/*L*
    5. 7.8 mg/*L*



CHAPTER 3

WELLS

by

Al Ward

and

John German

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OBJECTIVES

Chapter 3. WELLS

Chapter 3 is divided into two sections. In the first section we have assumed that you are responsible for the operation and maintenance of a well. In the second section (the Appendix) we have assumed that your responsibilities have been expanded and require the knowledge and skills necessary to select a well site, work with a well driller, test and evaluate pumps and wells, and also abandon and plug wells.

Following completion of Chapter 3, you should be able to:

1. Protect a well from contamination,
2. Identify the parts of a well and pump system,
3. Maintain and rehabilitate a well,
4. Operate and maintain a well pump and hydropneumatic pressure tank,
5. Inspect a well and pumping system,
6. Disinfect wells and pumps,
7. Keep accurate records of a well and pumping system,
8. Remove sand from water and mains, and
9. Troubleshoot a well and pumping system.

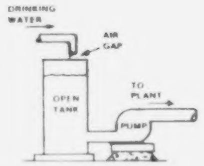
Following completion of the Appendix of Chapter 3 (optional), you should be able to:

1. Select a well site,
2. Describe the types of wells and drilling methods,
3. Test and evaluate a well and pump, and
4. Abandon and plug a well no longer productive or needed.

GLOSSARY

Chapter 3. WELLS

AIR GAP AIR GAP



An open vertical drop, or vertical empty space, that separates a drinking (potable) water supply to be protected from another water system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because there is no way raw water or any other water can reach the drinking water.

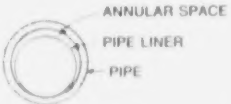
ALARM CONTACT ALARM CONTACT

A switch that operates when some pre-set low, high or abnormal condition exists.

ALLUVIAL (uh-LOU-vee-ul) ALLUVIAL

Relating to mud and/or sand deposited by flowing water. Alluvial deposits may occur after a heavy rain storm.

ANNULAR SPACE (AN-you-ler) ANNULAR SPACE



A ring-shaped space located between two circular objects, such as two pipes.

APPURTENANCE (uh-PURR-ten-nans) APPURTENANCE

Machinery, appliances, structures and other parts of the main structure necessary to allow it to operate as intended, but not considered part of the main structure.

AQUIFER (ACK-wi-fer) AQUIFER

A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

ARTESIAN (are-TEE-zhun) ARTESIAN

Pertaining to groundwater, a well or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given an opportunity to do so.

AVAILABLE CHLORINE AVAILABLE CHLORINE

A measure of the amount of chlorine available in chlorinated lime, hypochlorite compounds, and other materials that are used as a source of chlorine when compared with that of elemental (liquid or gaseous) chlorine.

BAILER (BAY-ler) BAILER

A 10- to 20-foot-long pipe equipped with a valve at the lower end. A bailer is used to remove slurry from the bottom or the side of a well as it is being drilled.

BOWLS, PUMP BOWLS, PUMP

The submerged pumping unit in a well, including the shaft, impeller and housing.

BRAKE HORSEPOWER BRAKE HORSEPOWER

(1) The horsepower required at the top or end of a pump shaft (input to a pump).

(2) The energy provided by a motor or other power source.

CAISSON (KAY-sawn) CAISSON

A structure or chamber which is usually sunk or lowered by digging from the inside. Used to gain access to the bottom of a stream or other body of water.

CAPILLARY ACTION CAPILLARY ACTION

The movement of water through very small spaces due to molecular forces.

CAPILLARY FORCES CAPILLARY FORCES

The molecular forces which cause the movement of water through very small spaces.

CENTRIFUGAL PUMP (sen-TRIF-uh-gull) CENTRIFUGAL PUMP

A pump consisting of an impeller fixed on a rotating shaft that is enclosed in a casing, and having an inlet and discharge connection. As the rotating impeller whirls the water around, centrifugal force builds up enough pressure to force the water through the discharge outlet.

CHECK VALVE CHECK VALVE

A special valve with a hinged disc or flap that opens in the direction of normal flow and is forced shut when flow attempts to go in the reverse or opposite direction of normal flow.

CIRCLE OF INFLUENCE CIRCLE OF INFLUENCE

The circular outer edge of a depression produced in the water table by the pumping of water from a well. Also see CONE OF INFLUENCE and CONE OF DEPRESSION.

CONDUCTOR CASING CONDUCTOR CASING

The outer casing of a well. The purpose of this casing is to prevent contaminants from surface waters or shallow groundwaters from entering a well.

CONE OF DEPRESSION CONE OF DEPRESSION

The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF INFLUENCE.

CONE OF INFLUENCE CONE OF INFLUENCE

The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF DEPRESSION.

CONSOLIDATED FORMATION CONSOLIDATED FORMATION

A geologic material whose particles are stratified (layered), cemented or firmly packed together (hard rock); usually occurring at a depth below the ground surface. Also see UNCONSOLIDATED FORMATION.

CONTACTOR CONTACTOR

An electrical switch, usually magnetically operated.

CONTAMINATION CONTAMINATION

The introduction into water of microorganisms, chemicals, toxic materials, wastes, or wastewater in a concentration that makes the water unfit for its intended use.

CONTROLLER CONTROLLER

A device which controls the starting, stopping or operation of a piece of equipment.

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving non-potable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

DATUM LINE DATUM LINE

A line from which heights and depths are calculated or measured. Also called a DATUM PLANE or a DATUM LEVEL.

DISCHARGE HEAD DISCHARGE HEAD

The pressure (in pounds per square inch or psi) measured at the centerline of a pump discharge and very close to the discharge flange, converted into feet.

Discharge Head, ft = (Discharge Pressure, psi)(2.31 ft/psi)

DRAWDOWN DRAWDOWN

(1) The drop in the water table or level of water in the ground when water is being pumped from a well.

(2) The amount of water used from a tank or reservoir.

(3) The drop in the water level of a tank or reservoir.

EFFECTIVE SIZE (E.S.) EFFECTIVE SIZE (E.S.)

The diameter of the particles in a granular sample (sand) for which 10 percent of the grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

ENERGY GRADE LINE (E.G.L.) ENERGY GRADE LINE (E.G.L.)

A line that represents the elevation of energy head of water flowing in a pipe, conduit or channel. The line is drawn above the hydraulic grade line (gradient) a distance equal to the velocity head ($V^2/2g$) of the water flowing at each section or point along the pipe or channel. Also see HYDRAULIC GRADIENT and HYDRAULIC GRADE LINE.

[SEE DRAWING ON NEXT PAGE]

EVAPORATION EVAPORATION

The process by which water or other liquid becomes a gas (water vapor or ammonia vapor).

FOOT VALVE FOOT VALVE

A special type of check valve located at the bottom end of the suction pipe on a pump. This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe.

GEOPHYSICAL LOG GEOPHYSICAL LOG

A record of the structure and composition of the earth encountered when drilling a well or similar type of test hole or boring.

HEAD HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

HEADER HEADER

A large pipe to which a series of smaller pipes are connected. Also called a MANIFOLD.

HEAT SENSOR HEAT SENSOR

A device which opens and closes a switch in response to changes in the temperature. This device might be a metal contact, or a thermocouple which generates a minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a TEMPERATURE SENSOR.

HYDRAULIC GRADE LINE (H.G.L.) HYDRAULIC GRADE LINE (H.G.L.)

The surface or profile of water flowing in an open channel or a pipe flowing partially full. If a pipe is under pressure, the hydraulic grade line is at the level water would rise to in a small tube connected to the pipe. Also see ENERGY GRADE LINE.

[SEE DRAWING ON NEXT PAGE]

HYDRAULIC GRADIENT HYDRAULIC GRADIENT

The slope of the hydraulic grade line. This is the slope of the water surface in an open channel, or the slope of the water surface of the groundwater table, or the slope of the water pressure for pipes under pressure.

HYDROGEOLOGIST (HI-dro-gee-ALL-uh-gist) HYDROGEOLOGIST

A person who studies and works with groundwater.

HYDROLOGIC CYCLE (HI-dro-LOJ-ick) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean. Also called the WATER CYCLE.

HYDROPNEUMATIC (HI-dro-new-MAT-ick) HYDROPNEUMATIC

A water system, usually small, in which a water pump is automatically controlled (started and stopped) by the air pressure in a compressed-air tank.

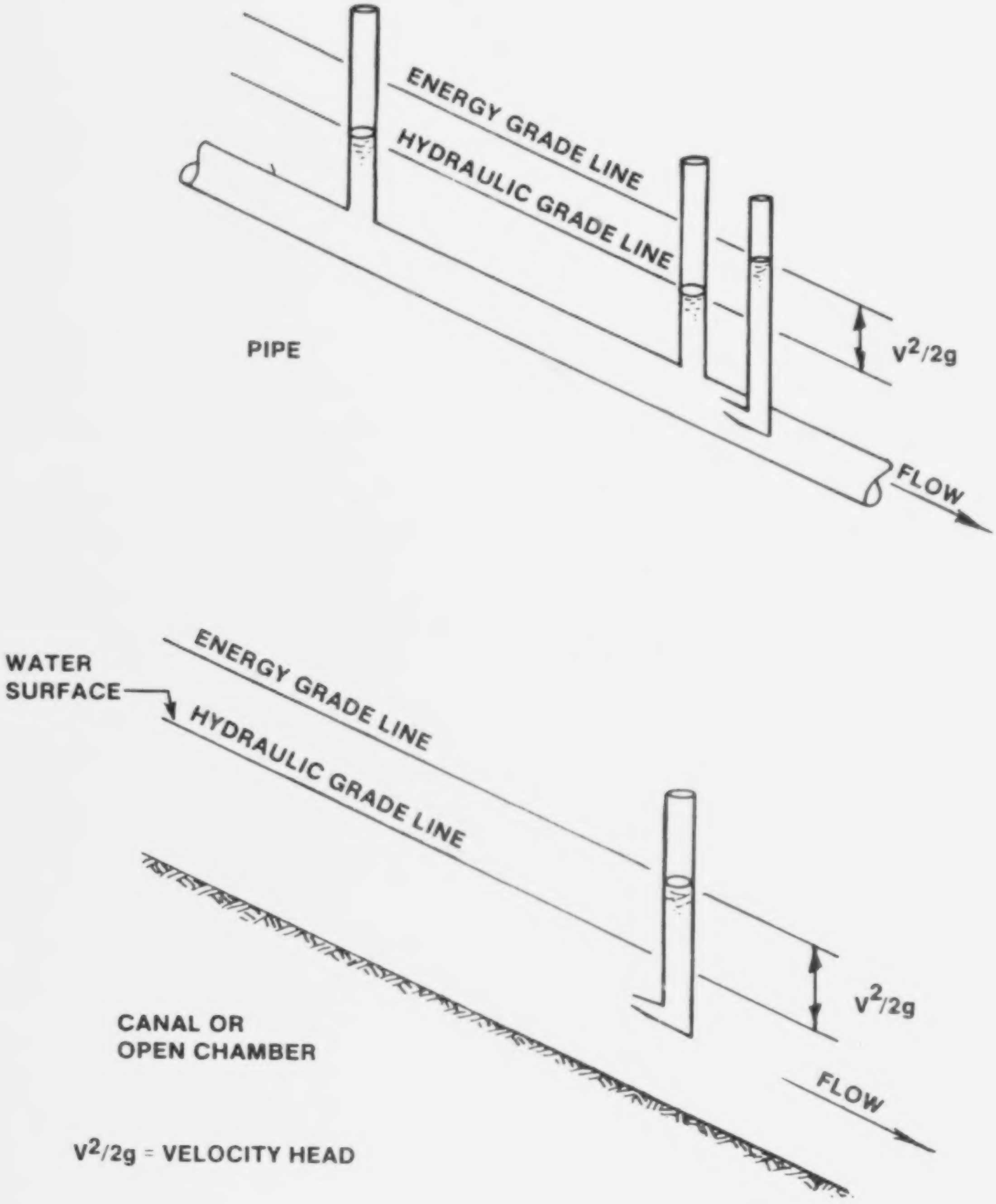
HYDROSTATIC PRESSURE (HI-dro-STAT-ick) HYDROSTATIC PRESSURE

(1) The pressure at a specific elevation exerted by a body of water at rest, or

(2) In the case of groundwater, the pressure at a specific elevation due to the weight of water at higher levels in the same zone of saturation.

IMPELLER IMPELLER

A rotating set of vanes in a pump designed to pump or lift water.


ENERGY GRADE LINE
HYDRAULIC GRADE LINE
$V^2/2g$
PIPE
FLOW
WATER SURFACE
ENERGY GRADE LINE
HYDRAULIC GRADE LINE
$V^2/2g$
CANAL OR OPEN CHAMBER
FLOW
$V^2/2g$ = VELOCITY HEAD

ENERGY GRADE LINE and HYDRAULIC GRADE LINE

INDICATOR (INSTRUMENT) INDICATOR

A device which indicates the result of a measurement. Most indicators in the water utility field use either a fixed scale and movable indicator (pointer) such as a pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called a RECEIVER.

INPUT HORSEPOWER INPUT HORSEPOWER

The total power used in operating a pump and motor.

$$\text{Input Horsepower, HP} = \frac{(\text{Brake Horsepower, HP})(100\%)}{\text{Motor Efficiency, }\%}$$

INTERLOCK INTERLOCK

An electrical switch, usually magnetically operated. Used to interrupt all (local) power to a panel or device when the door is opened or the circuit is exposed to service.

INTERSTICE (in-TUR-stuhz) INTERSTICE

A very small open space in a rock or granular material. Also called a void or void space. Also see PORE.

KELLY KELLY

The square section of a rod which causes the rotation of the drill bit. Torque from a drive table is applied to the square rod to cause the rotary motion. The drive table is chain or gear driven by an engine.

KINETIC ENERGY KINETIC ENERGY

Energy possessed by a moving body of matter, such as water, as a result of its motion.

LEATHERS LEATHERS

O rings or gaskets used with piston pumps to provide a seal between the piston and the side wall.

LEVEL CONTROLS LEVEL CONTROLS

A float device (or pressure switch) which senses changes in a measured variable and opens or closes a switch in response to that change. In its simplest form, this control might be a floating ball connected mechanically to a switch or a valve such as is used to stop water flow into a toilet when the tank is full.

LOGGING, ELECTRICAL LOGGING, ELECTRICAL

A procedure used to determine the porosity (spaces or voids) of formations in search of water-bearing formations (aquifers). Electrical probes are lowered into wells, an electrical current is induced at various depths, and the resistance measured of various formations indicates the porosity of the material.

MANIFOLD MANIFOLD

A large pipe to which a series of smaller pipes are connected. Also called a HEADER.

MANOMETER (man-NAH-mut-ter) MANOMETER

An instrument for measuring pressure. Usually a manometer is a glass tube filled with a liquid that is used to measure the difference in pressure across a flow-measuring device such as an orifice or venturi meter. The instrument used to measure blood pressure is a type of manometer.

MEASURED VARIABLE MEASURED VARIABLE

A characteristic or component part that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

MECHANICAL JOINT MECHANICAL JOINT

A flexible device that joins pipes or fittings together by the use of lugs and bolts.

MEG MEG

A procedure used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEGGER.

MEGGER (from "megohm") MEGGER

An instrument used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEG.

MESH MESH

One of the openings or spaces in a screen or woven fabric. The value of the mesh is usually given as the number of openings per inch. This value does not consider the diameter of the wire or fabric; therefore, the mesh number does not always have a definite relationship to the size of the hole.

MOTOR EFFICIENCY MOTOR EFFICIENCY

The ratio of energy delivered by a motor to the energy supplied to it during a fixed period or cycle. Motor efficiency ratings will vary depending upon motor manufacturer and usually will range from 88.9 to 90.0 percent.

NIOSH NIOSH

The **N**ational **I**nstitute of **O**ccupational **S**afety and **H**ealth is an organization that tests and approves safety equipment for particular applications. NIOSH is the primary Federal agency engaged in research in the national effort to eliminate on-the-job hazards to the health and safety of working people. The *NIOSH PUBLICATIONS CATALOG* contains a listing of NIOSH publications mainly on industrial hygiene and occupational health. To obtain a copy of the catalog, write to NIOSH Publications, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

NOMINAL DIAMETER NOMINAL DIAMETER

An approximate measurement of the diameter of a pipe. Although the nominal diameter is used to describe the size or diameter of a pipe, it is usually not the exact inside diameter of the pipe.

ORIFICE (OR-uh-fiss) ORIFICE

An opening (hole) in a plate, wall or partition.

OSHA (O-shuh) OSHA

The Williams-Steiger **O**ccupational **S**afety and **H**ealth **A**ct of 1970 is a law designed to protect the health and safety of industrial workers and also the operators of water supply systems and treatment plants.

OVERALL EFFICIENCY, PUMP OVERALL EFFICIENCY, PUMP

The combined efficiency of a pump and motor together. Also called the WIRE-TO-WATER EFFICIENCY.

OVERDRAFT OVERDRAFT

The pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin. This pumping results in a depletion or "mining" of the groundwater in the basin.

PACKER ASSEMBLY PACKER ASSEMBLY

An inflatable device used to seal the tremie pipe inside the well casing to prevent grout from entering the inside of the conductor casing.

PERCOLATING WATER (PURR-ko-LAY-ting) PERCOLATING WATER

Water that passes through soil or rocks under the force of gravity.

PERMEABILITY (PURR-me-uh-BILL-uh-tee) PERMEABILITY

The property of a material or soil that permits considerable movement of water through it when it is saturated

PET COCK PET COCK

A small valve or faucet used to drain a cylinder or fitting.

PITLESS ADAPTER PITLESS ADAPTER

A fitting which allows the well casing to be extended above ground while having a discharge connection located below the frost line. Advantages of using a pitless adapter include the elimination of the need for a pit or pump house and it is a water-tight design, which helps maintain a sanitary water supply.

POLLUTION POLLUTION

The impairment (reduction) of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes), to a degree that has an adverse effect on any beneficial use of water.

PORE PORE

A very small open space in a rock or granular material. Also see INTERSTICE.

POROSITY POROSITY

(1) A measure of the spaces or voids in a material or aquifer.

(2) The ratio of the volume of spaces in a rock or soil to the total volume. This ratio is usually expressed as a percentage.

$$\text{Porosity, \%} = \frac{(\text{Volume of Spaces})(100\%)}{\text{Total Volume}}$$

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

PRESSURE CONTROL PRESSURE CONTROL

A switch which operates on changes in pressure. Usually this is a diaphragm pressing against a spring. When the force on the diaphragm overcomes the spring pressure, the switch is actuated (activated).

PRIMARY ELEMENT PRIMARY ELEMENT

An instrument which measures (senses) a physical condition or variable of interest. Floats and thermocouples are examples of primary elements. Also called a SENSOR.

PRIME PRIME

The action of filling a pump casing with water to remove the air. Most pumps must be primed before startup or they will not pump any water.

PUMPING WATER LEVEL PUMPING WATER LEVEL

The vertical distance in feet from the centerline of the pump discharge to the level of the free pool while water is being drawn from the pool.

PURVEYOR, WATER (purr-VAY-or) PURVEYOR, WATER

An agency or person that supplies water (usually potable water).

RANNEY COLLECTOR RANNEY COLLECTOR

This water collector is constructed as a dug well from 12 to 16 feet (3.5 to 5 m) in diameter that has been sunk as a caisson near the bank of a river or lake. Screens are driven radially and approximately horizontally from this well into the sand and the gravel deposits underlying the river.

[SEE DRAWING ON NEXT PAGE]

RECEIVER RECEIVER

A device which indicates the result of a measurement. Most receivers in the water utility field use either a fixed scale and movable indicator (pointer) such as a pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called an INDICATOR.

RECORDER RECORDER

A device that creates a permanent record, on a paper chart or magnetic tape, of the changes of some measured variable.

SAFE YIELD SAFE YIELD

The annual quantity of water that can be taken from a source of supply over a period of years without depleting the source permanently (beyond its ability to be replenished naturally in "wet years").

SENSOR SENSOR

An instrument which measures (senses) a physical condition or variable of interest. Floats and thermocouples are examples of sensors. Also called a PRIMARY ELEMENT.

SET POINT SET POINT

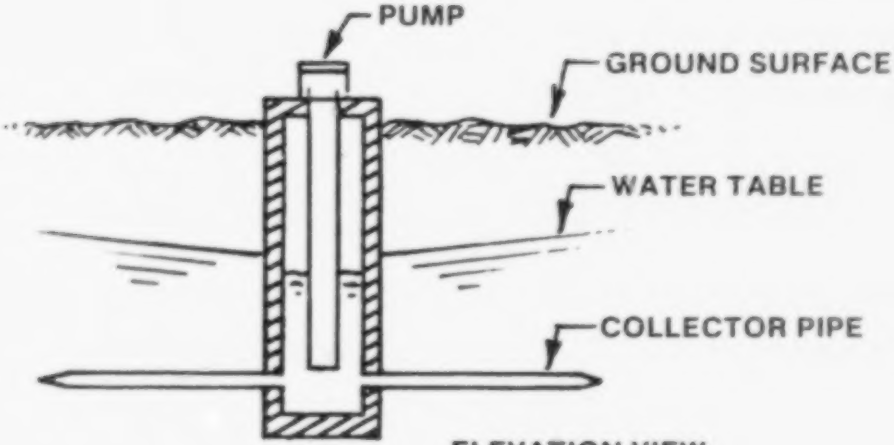
The position at which the control or controller is set. This is the same as the desired value of a process variable or level in a tank.

SLURRY (SLUR-e) SLURRY

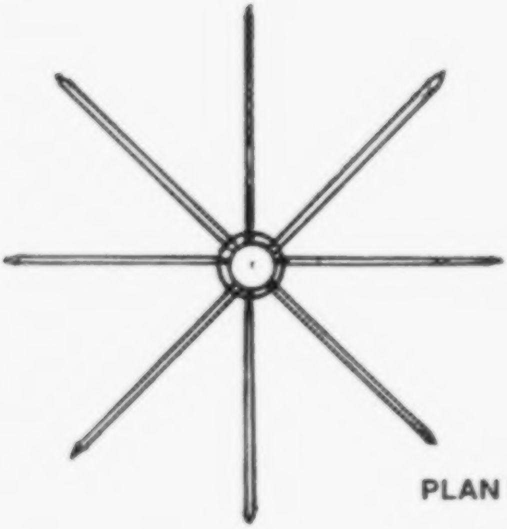
A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SOLENOID (SO-luh-noid) SOLENOID

A magnetically (electrical coil) operated mechanical device. Solenoids can be a small valve or a switch.


PUMP
GROUND SURFACE
WATER TABLE
COLLECTOR PIPE

ELEVATION VIEW



PLAN VIEW OF COLLECTOR PIPES

RANNEY COLLECTOR

SOUNDING TUBE SOUNDING TUBE

A pipe or tube used for measuring the depths of water.

SPECIFIC YIELD SPECIFIC YIELD

The quantity of water that a unit volume of saturated permeable rock or soil will yield when drained by gravity. Specific yield may be expressed as a ratio or as a percentage by volume.

STARTERS STARTERS

Devices used to start up large motors gradually to avoid severe mechanical shock to a driven machine and to prevent disturbance to the electrical lines (causing dimming and flickering of lights).

STATIC WATER DEPTH STATIC WATER DEPTH

The vertical distance in feet from the centerline of the pump discharge down to the surface level of the free pool while no water is being drawn from the pool or water table.

STATIC WATER LEVEL STATIC WATER LEVEL

(1) The elevation or level of the water table in a well when the pump is not operating.

(2) The level or elevation to which water would rise in a tube connected to an artesian aquifer, or basin, or conduit under pressure.

SUBSIDENCE (sub-SIDE-ence) SUBSIDENCE

The dropping or lowering of the ground surface as a result of removing excess water (overdraft or over pumping) from an aquifer. After excess water has been removed, the soil will settle, become compacted and the ground surface will drop.

SUCTION LIFT SUCTION LIFT

The *NEGATIVE* pressure [in feet (meters) of water or inches (centimeters) of mercury vacuum] on the suction side of a pump. The pressure can be measured from the centerline of the pump *DOWN TO* (lift) the elevation of the hydraulic grade line on the suction side of the pump.

TIME LAG TIME LAG

The time required for processes and control systems to respond to a signal or reach a desired level.

TIMER TIMER

A device for automatically starting or stopping a machine or other device at a given time.

TRANSDUCER (trans-DUE-sir) TRANSDUCER

A device which senses some varying condition and converts it to an electrical signal for transmission to some other device (a receiver) for processing or decision making.

TRANSMISSIVITY (TRANS-miss-SIV-ity) TRANSMISSIVITY

A measure of the ability to transmit (as in the ability of an aquifer to transmit water).

TRANSPIRATION (TRAN-spur-RAY-shun) TRANSPIRATION

The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.

TREMIE (TREH-mie) TREMIE

A device used to place concrete or grout under water.

UNCONSOLIDATED FORMATION UNCONSOLIDATED FORMATION

A sediment that is loosely arranged or unstratified (not in layers) or whose particles are not cemented together (soft rock); occurring either at the ground surface or at a depth. Also see CONSOLIDATED FORMATION.

UNIFORMITY COEFFICIENT (U.C.) UNIFORMITY COEFFICIENT (U.C.)

The ratio of (1) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through.

$$\text{Uniformity Coefficient} = \frac{\text{Particle Diameter, 60\%}}{\text{Particle Diameter, 10\%}}$$

VARIABLE FREQUENCY DRIVE VARIABLE FREQUENCY DRIVE

A control system which allows the frequency of the current applied to a motor to be varied. The motor is connected to a low-frequency source while standing still; the frequency is then increased gradually until the motor and pump (or other driven machine) is at the desired speed.

VARIABLE, MEASURED VARIABLE, MEASURED

A factor (flow, temperature) that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

VELOCITY HEAD VELOCITY HEAD

The energy in flowing water as determined by a vertical height (in feet or meters) equal to the square of the velocity of flowing water divided by twice the acceleration due to gravity ($V^2/2g$).

VOLATILE (VOL-uh-tull) VOLATILE

A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.

WATER HAMMER WATER HAMMER

The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.

WATER TABLE WATER TABLE

The upper surface of the zone of saturation in an unconfined aquifer.

WELL LOG WELL LOG

A record of the thickness and characteristics of the soil, rock and water-bearing formations encountered during the drilling (sinking) of a well.

WIRE-TO-WATER EFFICIENCY WIERE-TO-WATER EFFICIENCY

The efficiency of a pump and motor together. Also called the OVERALL EFFICIENCY.

YIELD YIELD

The quantity of water (expressed as a rate of flow — GPM, GPH, GPD, or total quantity per year) that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic considerations. Also see SAFE YIELD.

ZONE OF SATURATION ZONE OF SATURATION

The soil or rock located below the water table. By definition, the zone of saturation is saturated with water. Also see WATER TABLE.

Hi-dro-gee-OL-e-gist
and friend...

CHAPTER 3. WELLS

(Lesson 1 of 4 Lessons)

3.0 GROUNDWATER — CRITICAL LINK TO WELLS

3.00 Importance of Groundwater

The function of a well is to intercept groundwater moving through *AQUIFERS*[1] and bring water to the surface for use by people. Although we are concerned with wells and their construction and maintenance, we must also be concerned with the lifeline to these wells. The aquifers and the quality of water in the aquifers must be maintained if we are going to preserve this precious source of water. Pollution and misuse of the aquifers can seriously affect a good water source. Pollution can render a supply useless while excessive use of our wells can affect both volume and rate of output causing permanent damage to the water-bearing formations of the Earth's surface.

3.000 Pollution

Groundwater moves very slowly through the soil purifying itself of suspended particles as it travels. If water should be contaminated on its journey to a well and the distance from the source of contamination is far, there is a possibility that we will not see adverse effects at the well. The soil mantle acts as a natural filter for suspended material to bring us a good, clean product. Unfortunately, the soil mantle does not always filter out or remove dissolved pollutants and contaminants (such as organic chemicals) found in water. Also, if sources of pollution are allowed to increase without limit and without regard to proximity to our wells, the Earth's surface will become saturated with pollutants which no known treatment process can remove. Since water moves so slowly through the soil, we may end up with a water supply that cannot be used for years, even after the sources of pollution are eliminated. Aquifers contaminated with oil spills and other chemical problems are almost impossible to clean up.

The well operator has a responsibility to preserve the quality of wells through preventive maintenance of the aquifers. Be alert for any construction that might result in wastes entering the groundwater stream. Septic tanks, subsurface leaching systems, mining operations, agricultural practices, solid waste disposal sites, and wastewater collection facilities are all potential sources of groundwater pollution. Any such activity should be reported to the proper authorities so that adequate safeguards can be taken. Also you must make sure that none of your wells allow direct contamination of an aquifer due to inadequate grouting or seals. Although unsanitary conditions are not as common in the United States as in some countries, they still pose potential problems to our groundwater supplies.

Operators must always be alert for potential sources of groundwater pollution to the aquifers providing drinking water to their communities. Some of the possible sources include:[2]

1. Leaks from oil and gas pipelines,
2. Leaks from storage tanks,
3. Fertilizers, pesticides and irrigation water,
4. Improper management of animal wastes,
5. Liquid wastes and solid-waste tailing piles from surface and underground mining operations,
6. Drainage from abandoned mines,
7. Salt water encroachment from saline aquifers and the ocean,
8. Improper construction and use of injection wells for the disposal of industrial, nuclear and hazardous wastes,
9. Accidental spills or liquid wastes, toxic fuels, gasoline and oil, and
10. Abandoned wells which were not properly plugged.

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[1] *Aquifer (ACK-wi-fer). A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.*

[2] *Source: The Johnson Drillers Journal, Second Quarter, 1982.*

3.001 *Overdraft*[3]

All of our wells have a certain *YIELD*[4] that can normally be replaced each year through recharge due mainly to precipitation. This yield, commonly called *SPECIFIC YIELD*,[5] is determined during well development through analysis by a qualified *HYDROGEOLOGIST*.[6] Overdraft (overpumping) of the well can cause permanent damage to the water storage and transmitting properties of the aquifers. After excess water has been removed (overdraft) from an aquifer the soil may settle and cause compaction of the aquifers, which results in closing the *PORES*[7] through which water moves and in which the water is stored. This compaction and closing of pores also produces what we call subsidence (sub-SIDE-ence) of the land. Over the past three decades, ground subsidence has been measured from 0.91 feet (0.27 meters) in Savannah, Georgia to over 27 feet (8 meters) in the San Joaquin Valley in California. Sink holes in Florida can also be attributed to overdraft of the groundwater supplies.

3.002 *Geologic and Hydrologic Data*

If operators are going to protect aquifers, something must be known about them. Recordkeeping can be an invaluable tool for understanding the aquifer and its performance. Geologic data from the well driller's logs (records of depths of various layers of soil and type of soil in each layer), mining operations in the area, and data from the U.S. Soil Conservation Service and from other sources will help operators to understand how water is getting into a well. Consultation with a geologist is recommended for a more complete understanding of the underground formation.

Records of pumping amounts and dates, depths of water at start and end of pumping, time of pumping, and water quality results remain the best sources of information about a well's performance. Using past performance data, an engineer, hydrologist, geologist and well operator can predict the well's performance with a high degree of accuracy. Recordkeeping is very important and it is not possible for operators to accumulate too much information. So, if records are not now being kept, a program should be started immediately.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 115.

3.0A What is the purpose of a well?

3.0B List two potential problems that can affect wells.

3.0C How can an operator protect an aquifer?

3.0D What problems can be caused by the overdraft of a groundwater supply?

3.01 Origin, Occurrence, and Movement of Groundwater

3.010 *Hydrologic Cycle*[8] *(Figures 3.1 and 3.2)*

The Earth's water cycle, or hydrologic cycle, is the continuous circulation of water (including moisture) on our planet. The cycle has neither a beginning nor an end, but the concept of the hydrologic cycle commonly begins with the waters of the ocean, since they cover about three-fourths of the Earth's surface (see Section 2.10, Hydrologic Cycle for details).

3.011 *Soil Moisture and Groundwater*

Water that infiltrates the soil is called subsurface water, but not all of it becomes groundwater. Basically, three things may happen to that water. First, it may be pulled back to the surface by capillary forces and be *EVAPORATED*[9] into the atmosphere, thus skipping much of the journey through the water cycle we have described. Second, it may be absorbed by plant roots growing in the soil and then re-enter the atmosphere by a process known as *TRANSPIRATION*.[10] Third, water that has infiltrated the soil deeply enough may be pulled on downward by gravity until it reaches the level of the *ZONE OF SATURATION*[11] — *THE GROUNDWATER RESERVOIR THAT SUPPLIES WATER TO WELLS.*

Groundwater conditions directly affect the design, operation, and performance of a water well. For a saturated material to qualify as an aquifer, it must have: (1) *POROSITY*,[12] area, and thickness sufficient to store an adequate water supply; (2) sufficient specific yield to allow the stored water to drain into a well; and (3) hydraulic *TRANSMISSIVITY*[13] to permit a well to drain water from the aquifer fast enough to meet flow requirements.

3.012 *Importance of Groundwater in the United States*

Approximately 45 percent of the water used in the United States comes from underground sources. In many locations, water from wells or springs is the only water available to a community. Estimates indicate that there are between

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[3] *Overdraft. The pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin. This pumping results in a depletion or "mining" of the groundwater in the basin.*

[4] *Yield. The quantity of water (expressed as a rate of flow — GPM, GPH, GPD, or total quantity per year), that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic considerations.*

[5] *Specific Yield. The quantity of water that a unit volume of saturated permeable rock or soil will yield when drained by gravity. Specific yield may be expressed as a ratio or as a percentage by volume.*

[6] *Hydrogeologist (HI-dro-gee-ALL-uh-gist). A person who studies and works with groundwater.*

[7] *Pore. A very small open space in a rock or granular material.*

[8] *Hydrologic Cycle (HI-dro-LOJ-ick). The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean.*

[9] *Evaporation. The process by which water or other liquid becomes a vapor (water vapor or ammonia vapor).*

[10] *Transpiration (TRAN-spur-RAY-shun). The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating.*

[11] *Zone of Saturation. The soil or rock located below the water table. By definition, the zone of saturation is saturated with water.*

[12] *Porosity. (1) A measure of the spaces or voids in a material or aquifer. (2) The ratio of the volume of spaces in a rock or soil to the total volume. This ratio is usually expressed as a percentage.*

$$\text{Porosity, \%} = \frac{(\text{Volume of Spaces})(100\%)}{\text{Total Volume}}$$

[13] *Transmissivity (TRANS-miss-SIV-ity). A measure of the ability to transmit (as in the ability of an aquifer to transmit water).*

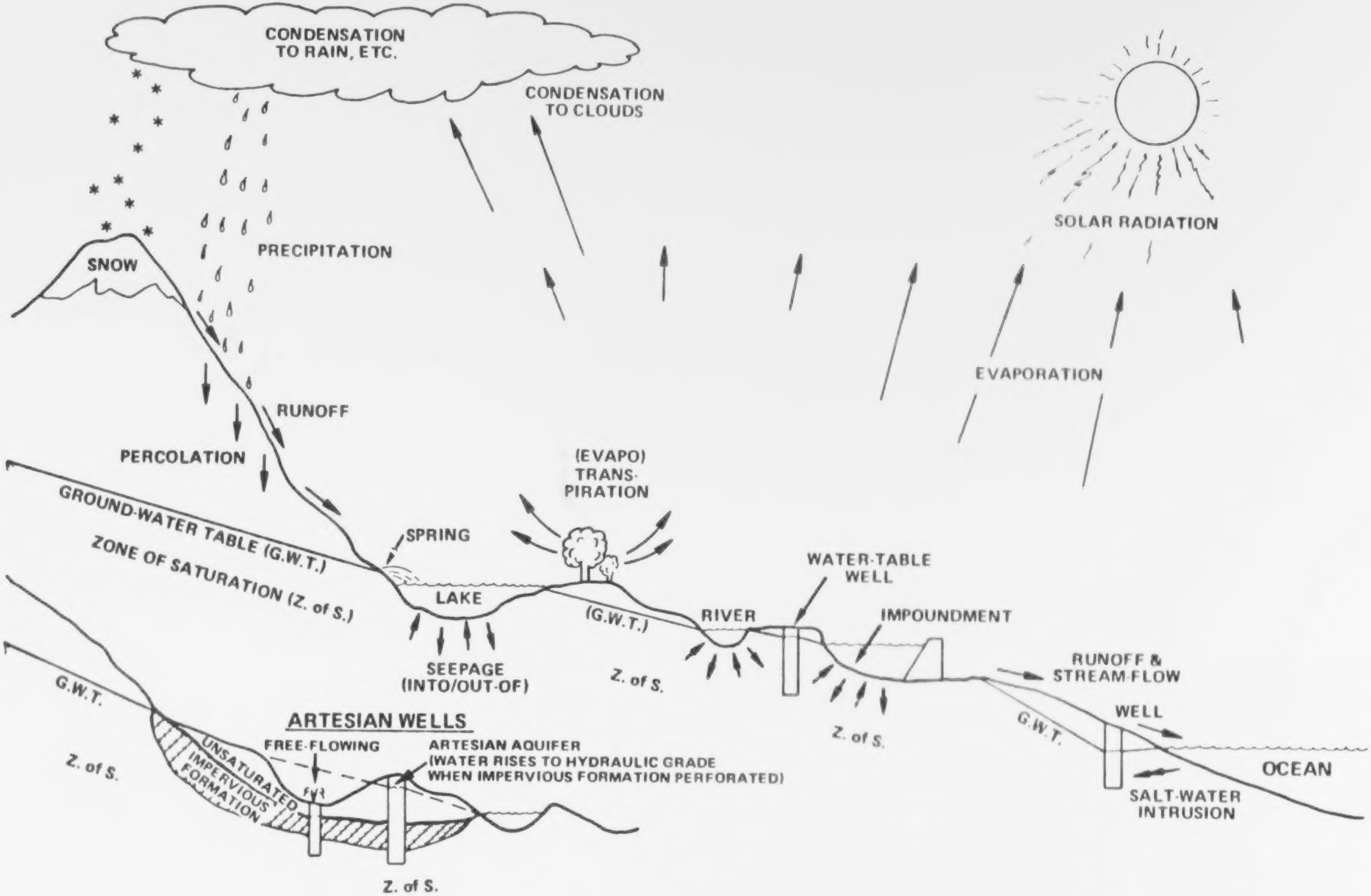
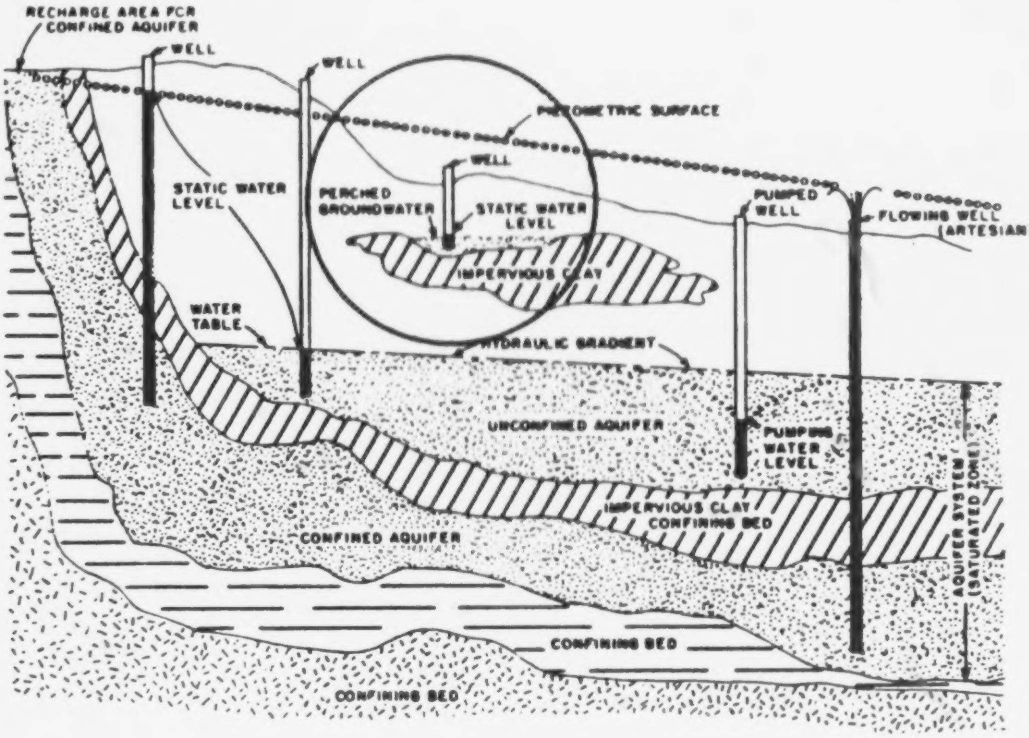

CONDENSATION TO RAIN, ETC.
CONDENSATION TO CLOUDS
SOLAR RADIATION
SNOW
PRECIPITATION
EVAPORATION
RUNOFF
PERCOLATION
(EVAPO) TRANS-PIRATION
GROUND-WATER TABLE (G.W.T.)
SPRING
ZONE OF SATURATION (Z. of S.)
LAKE
(G.W.T.)
WATER-TABLE WELL
RIVER
IMPOUNDMENT
SEEPAGE (INTO/OUT-OF)
Z. of S.
RUNOFF & STREAM-FLOW
G.W.T.
ARTESIAN WELLS
Z. of S.
G.W.T.
WELL
FREE-FLOWING
ARTESIAN AQUIFER (WATER RISES TO HYDRAULIC GRADE WHEN IMPERVIOUS FORMATION PERFORATED)
UNSATURATED
IMPERVIOUS FORMATION
OCEAN
Z. of S.
SALT-WATER INTRUSION
Z. of S.

Fig. 3.1 The hydrologic cycle as related to water supply

(Source: *BASIC WATER TREATMENT OPERATOR TRAINING COURSE I,* by Leonard Ainsworth, by permission of California-Nevada Section AWWA)


RECHARGE AREA FCR
CONFINED AQUIFER
WELL
WELL
PIEZOMETRIC SURFACE
WELL
STATIC WATER
LEVEL
PERCHED
GROUNDWATER
STATIC WATER
LEVEL
IMPERVIOUS CLAY
PUMPED
WELL
FLOWING WELL
(ARTESIAN)
WATER
TABLE
HYDRAULIC GRADIENT
UNCONFINED AQUIFER
PUMPING
WATER
LEVEL
AQUIFER SYSTEM
(SATURATED ZONE)
IMPERVIOUS CLAY
CONFINING BED
CONFINED AQUIFER
CONFINING BED
CONFINING BED

Note perched aquifer inside circle

Fig. 3.2 Hydrologic cycle as related to groundwater

Source: *WATER WELLS AND PUMPS: THEIR DESIGN, CONSTRUCTION, OPERATION AND MAINTENANCE*, Division of Agricultural Sciences, University of California, Davis)

10,000,000 and 20,000,000 water wells scattered throughout the United States. Most are situated in valleys or river-bottom land, although many are located in hilly and mountainous regions. They range from shallow hand-dug wells to carefully designed, large production wells.

The principal reasons for using groundwater are:

1. Groundwater is generally available in most localities although quantities may be very limited in certain areas;
2. Well and pumping facilities cost less than surface treatment facilities;
3. They are usually clear and, with few exceptions, can meet turbidity requirements;
4. Conditions for growth and survival of bacteria and virus in groundwater are generally unfavorable when compared with surface waters;
5. The mineral content for a given well is usually uniform;
6. Well water usually has a more constant and lower temperature during the summer, and
7. *WELL SUPPLIES ARE PARTICULARLY SUITED TO THE NEEDS OF SMALLER COMMUNITIES IN MANY AREAS.*

3.02 Summary

YOU, as an operator, have as much of a responsibility to preserve the quality and capacities of your wells as you do to oil the bearings on your pumps. The damage from neglect and excessive use of aquifers is sometimes irreversible. You can and should:

1. Be on the outlook for any possible sources of pollution of groundwater in the area around the well,

2. Be careful not to overtax the capability of aquifers to supply water by installing oversized pumps,
3. Insure that all wells are properly sealed to prevent direct contamination of the aquifer, and
4. Develop a recordkeeping program of well production and quality. These records should include geologic as well as hydrologic and hydraulic data gathered during the construction and testing of the well.

The importance of preservation and maintenance of the water supply source cannot be overstated. You are a primary link between groundwater and wells.

3.03 Additional Reading

1. Environmental Protection Agency, *MANUAL OF INDIVIDUAL WATER SUPPLY SYSTEMS*, Office of Water Programs, Water Supply Division, 1973 (EPA 430 9-74007). For sale by the U.S. Department of Commerce, National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22161. Price $15.00.
2. *GROUND WATER AND WELLS*, Johnson Division, UOP, Box 43118, St. Paul, Minnesota 55164. Price, $15.00

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 115.

3.0E What is the hydrologic cycle?

3.0F List as many of the principal reasons as you can recall for using groundwater.

3.1 SURFACE FEATURES OF A WELL

3.10 Purpose of Surface Features

A number of openings are found in the top of a well. These openings are designed to provide access to the well for taking water level measurements, permitting entrance or escape of air or gas, adding gravel, or for applying disinfection or well cleaning agents. These openings must be protected against the entrance of surface waters or foreign matter. Next to the sanitary seal, this is the most important sanitary feature of well construction.

Figure 3.3 is a cross-sectional drawing showing the typical surface features of a domestic water well. Many of the component parts we will be discussing in the following pages are referenced to this drawing. Study this drawing and become familiar with the basic parts and their relationship to the entire facility.

3.11 Well-Casing Vent

A well-casing vent is provided to prevent vacuum conditions inside a well by admitting air during the *DRAWDOWN*[14] period when the well pump is first started. If vacuum conditions are allowed to develop, contamination may be sucked into the well through some hidden defect in the well or *CONDUCTOR CASING*,[15] or through the top of the well at the pump base.

The well-casing vent also serves to prevent pressure buildup inside the well casing by allowing excess air to escape during the well recovery (refilling) period after the well pump shuts off. If pressures are allowed to build up, they will loosen and blow out the sealing compound around the pump base.

A properly sized and constructed vent should allow the unrestricted flow of air into and out of the well interior. A vent of at least three inches (75 mm) in diameter should be provided. Dual venting is desirable on wells over 14 inches (350 mm) in diameter.

All well vents should be constructed so that openings are in a vertical downward position. Openings should be a minimum of thirty-six inches (900 mm) in height above the finished surface of the well lot (yard) and should be covered with a fine mesh screen or similar device to keep small insects from the well interior.

3.12 Gravel Tube

On gravel-envelope wells, a gravel tube must be provided to monitor the level of gravel and to add gravel as necessary. A typical gravel tube is 4 inches (100 mm) in diameter and is capped at the top end. Such openings must be elevated above ground level to prevent well contamination during flooding, and must be kept tightly sealed.

3.13 Sounding Tube[16]

A sounding tube is necessary so that the water level in the well can be periodically determined. This tube can also be used for the addition of chlorine and well-cleaning agents. The sounding tube is generally a minimum of 2 inches (50 mm) in diameter and must be kept tightly sealed. The water level is determined by inserting a disinfected rope or measuring tape into the tube, lowering it down to the water level and recording the distance. Often, the well casing vent is also used as a sounding tube by installing a tee in the well casing vent.

All vent pipes, sounding lines, and gravel fill pipes must be one continuous conduit through the concrete pedestal. Also, all conduits which penetrate the casings must be provided with a continuous watertight weld at the point of entry into the well interior.

3.14 Air Line Water Level Measuring Device

If a water level sounding line is to be incorporated, it may be installed either through the upper portion of the concrete pump pedestal or through the pump base. If installed within the concrete pump pedestal, a conduit of sufficient diameter to allow the passage of the sounding line is placed in the pedestal form prior to the placement of concrete. One-quarter inch (6 mm) galvanized pipe or schedule 80 PVC plastic pipe is frequently used as a sounding line. The space between the sounding line and the conduit or the openings around the line passing through the pump base must be provided with a watertight seal.

A quick-disconnect fitting on the sounding line is preferable to a permanent gage installation. To determine the distance to the water level, air pressure is applied to the

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[14] *Drawdown. (1) The drop in the water table or level of water in the ground when water is being pumped from a well, (2) the amount of water used from a tank or reservoir, and (3) the drop in the water level of a tank or reservoir.*

[15] *Conductor Casing. The outer casing of a well. The purpose of this casing is to prevent contaminants from surface waters or shallow groundwaters from entering a well.*

[16] *Sounding Tube. A pipe or tube used for measuring the depths of water.*

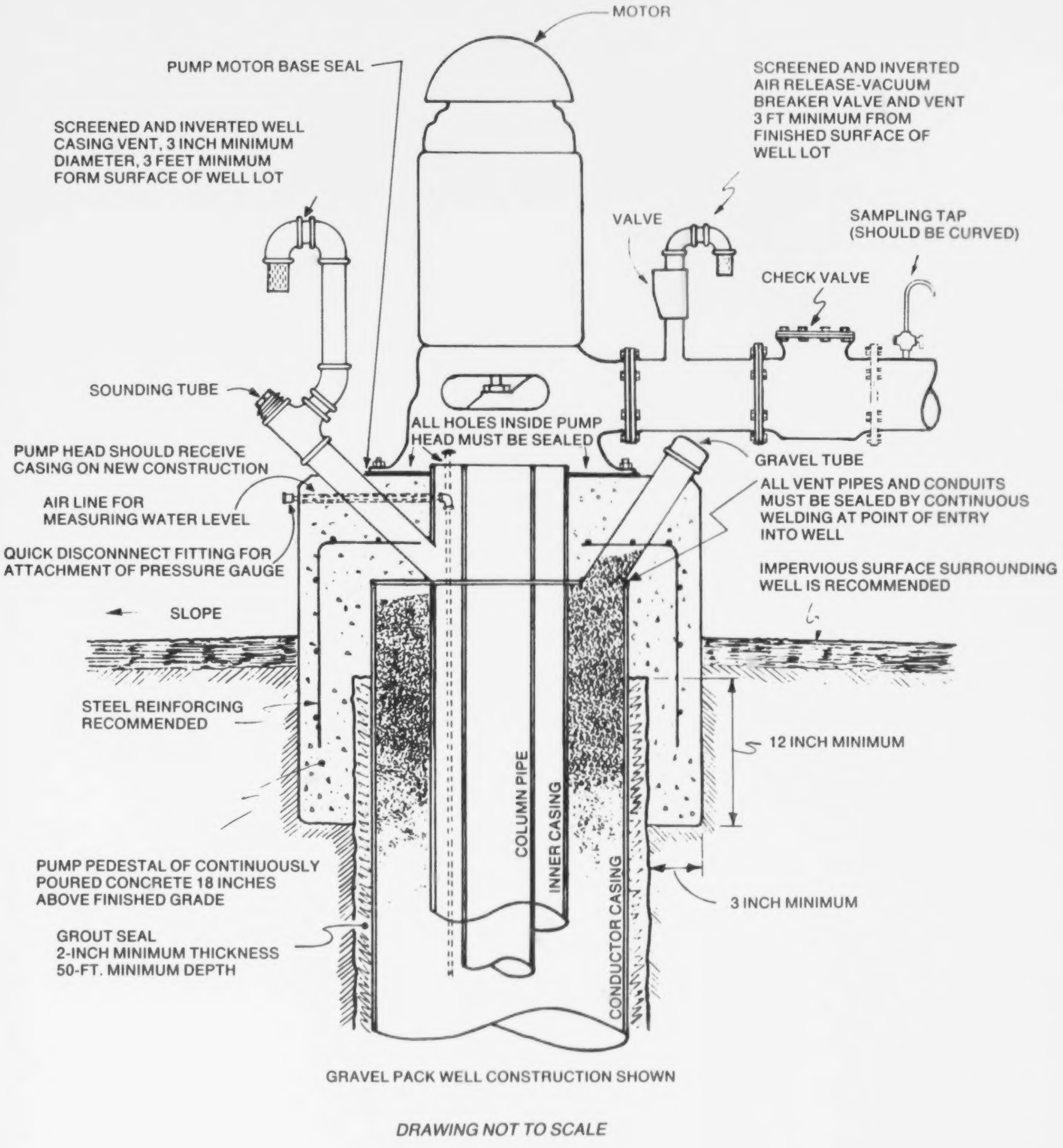
MOTOR
PUMP MOTOR BASE SEAL
SCREENED AND INVERTED AIR RELEASE-VACUUM BREAKER VALVE AND VENT 3 FT MINIMUM FROM FINISHED SURFACE OF WELL LOT
SCREENED AND INVERTED WELL CASING VENT, 3 INCH MINIMUM DIAMETER, 3 FEET MINIMUM FORM SURFACE OF WELL LOT
VALVE
SAMPLING TAP (SHOULD BE CURVED)
CHECK VALVE
SOUNDING TUBE
ALL HOLES INSIDE PUMP HEAD MUST BE SEALED
PUMP HEAD SHOULD RECEIVE CASING ON NEW CONSTRUCTION
GRAVEL TUBE
ALL VENT PIPES AND CONDUITS MUST BE SEALED BY CONTINUOUS WELDING AT POINT OF ENTRY INTO WELL
AIR LINE FOR MEASURING WATER LEVEL
QUICK DISCONNNECT FITTING FOR ATTACHMENT OF PRESSURE GAUGE
IMPERVIOUS SURFACE SURROUNDING WELL IS RECOMMENDED
SLOPE
STEEL REINFORCING RECOMMENDED
12 INCH MINIMUM
COLUMN PIPE
INNER CASING
CONDUCTOR CASING
PUMP PEDESTAL OF CONTINUOUSLY POURED CONCRETE 18 INCHES ABOVE FINISHED GRADE
3 INCH MINIMUM
GROUT SEAL
2-INCH MINIMUM THICKNESS
50-FT. MINIMUM DEPTH
GRAVEL PACK WELL CONSTRUCTION SHOWN
DRAWING NOT TO SCALE

Fig. 3.3 Surface features of a domestic water well

sounding line to force out all water. The pressure is measured and the measurement is converted to the depth of water in the line.

$$\text{Water Depth in Line, ft} = (\text{Air Pressure, psi})(2.31 \text{ ft water/psi})$$

The length of the line must be known to determine the distance down to the surface of the water.

$$\text{Water Surface, ft} = \text{Length of Line, ft} - \text{Water Depth in Line, ft}$$

3.15 Pump Pedestal

The well casing vent pipe and the gravel tube are generally encased within a concrete pump pedestal designed to support the full weight of the pumping unit.

The pump pedestal should be constructed of continuously-poured concrete to a minimum height of eighteen inches (450 mm) above the finished elevation of the well lot. A lower pedestal height may be used due to lack of space (entrance to tank less than 18 inches above floor), but in no case should the pedestal height be less than twelve inches (300 mm).

The size of the pump pedestal may vary depending upon the given installation, but in all cases must provide a minimum of three inches (75 mm) of concrete around the outside of the conductor casing grout seal, if one is used. The pedestal should extend down to enclose the top of the grout seal a minimum depth of twelve inches (300 mm). Steel reinforcement of the pedestal is recommended.

3.16 Pump Motor Base Seal

A watertight seal should be provided between the pump motor base and the concrete pedestal. If the two surfaces are parallel, a neoprene rubber seal cut from flat stock can be used. In many cases, however, these two surfaces are not parallel because wedges may have been installed to correctly align the pump head shaft in the center of the motor hollow-shaft unit. When this occurs, an oil-resistant, non-hardening material such as latex rubber can be used to create a seal. Cement grout is not recommended because it will eventually crack and create openings through the seal. A neoprene rubber or regular gasket material seal is very satisfactory for a submersible pump installation.

3.17 Sampling Taps

A sampling tap is generally provided on the downstream side of the pump check valve. A *PET COCK*[17] valve fitted with a three-eighths inch (9 mm) copper line with the outlet turned down towards the ground is recommended. No hose bib, faucet, or any other threaded valve should be installed between the well pump and the check valve. This is to prevent any contaminated water from being sucked into the well when the pump shuts down and the water column drains back into the well.

3.18 Air Release-Vacuum Breaker Valves

If a pump is not equipped with a *FOOT VALVE*[18] and you want to discharge the air in the column pipe, install an air release-vacuum breaker valve in the piping between the pump head and well discharge check valve. The valve functions as follows:

1. When the well pump is initially started, air inside the pump column is expelled (forced out) through the valve to the atmosphere instead of into the system;
2. When the well pump is shut down, air is admitted into the pump column, thus freely allowing the column to dewater into the well;
3. The valve should be mounted as close as possible to the check valve in a vertical position on top of the discharge piping; and
4. The opening in the top of the valve must be equipped with a downturned screened assembly, and be protected from flooding.

3.19 Pump Blowoff

The pump blowoff or drain line is used to remove initially pumped water containing sand away from the system. When there is a blowoff or drain line from the pump discharge or from a pump control valve the waste line must be located above any known flood levels and protected against the possibility of backsiphonage or back pressure. The blowoff or drain line should not be directly connected to any sewer or storm drain.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 115.

3.1A Why are there openings into the top of a well?

3.1B What is the purpose of the well-casing vent?

3.1C How would you determine the distance down to the water level in a well?

End of Lesson 1 of 4 Lessons on WELLS

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[17] *Pet Cock. A small valve or faucet used to drain a cylinder or fitting.*

[18] *Foot Valve. A special type of check valve located at the bottom of the suction pipe on a pump. This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe.*

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. WELLS

(Lesson 1 of 4 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions which you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson.

Write the answers to these questions in your notebook before continuing.

1. What kind of preventive maintenance program would you develop for an aquifer serving your wells?
2. How would you protect an aquifer from overdraft damage?
3. What are the major responsibilities of an operator with regard to an aquifer and well pump system?
4. What is the purpose of a pump blowoff?
5. Why should hose bibs, faucets or threaded valves not be installed between the well pump and the check valve?

Chapter 3. WELLS

Lesson 2 of 4 Lessons)

3.2 WELL APPURTENANCES[19]

3.20 Typical Well Pump and Pressure Tank

The well appurtenances described and shown in this section are illustrated in Figure 3.4 which is an elevation or profile drawing of a well pump and tank installation. This is a *TYPICAL* well pump-tank installation showing the general features and location of the appurtenances under discussion. Many variations of this layout are possible depending upon geographic location, state and local building and plumbing codes, hydraulic factors, and individual preferences.

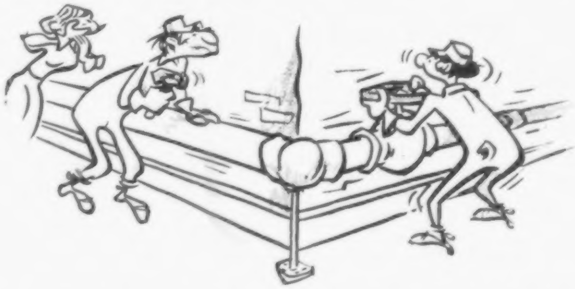
3.21 Valves

3.210 Check Valves[20]

Most well pump stations are equipped with some type of check valve installed on the discharge side of the pump. The purpose of the check valve is to act as the automatic shutoff valve when the pump stops. This valve prevents draining of the system or tank being pumped to, and keeps pressurized water from flowing back down the pump column into the well. This reversal of pressurized flow into a well can cause serious problems that may include removal of the pump from service and redevelopment of the well. (This flow reversal problem does not occur in well pump installations equipped with a foot valve.)

Several different types of check valves are available such as swing check, lift check, foot check, slant disc check, flap check, double disc check, and automatic control check. Four different types of check valves are illustrated in Figure 3.5.

The important features of any check valve are that the valve must (1) close watertight; (2) be able to safely withstand hydraulic shock loads; (3) have a low head loss; and, most importantly, (4) be equipped to close the valve disc in advance of flow reversal.



There are numerous ways to insure rapid shutoff of the valve disc within the recommended time of 1/20 to 1/10 of a second. This can be accomplished with an outside lever and weight (most commonly used), spring loaded (either internal or external) (spring closes the disc), and compressed air assisted (compressed air moves arm and closes disc).

3.211 Pump Control Valves

A pump control valve is a diaphragm-type valve designed to eliminate pipeline surges caused by the starting and

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[19] *Appurtenance (uh-PURR-ten-nans). Machinery, appliances, structures and other parts of the main structure necessary to allow it to operate as intended, but not considered part of the main structure.*

[20] *Check Valve. A special valve with a hinged disc or flap that opens in the direction of normal flow and is forced shut when flow attempts to go in the reverse or opposite direction of normal flow.*

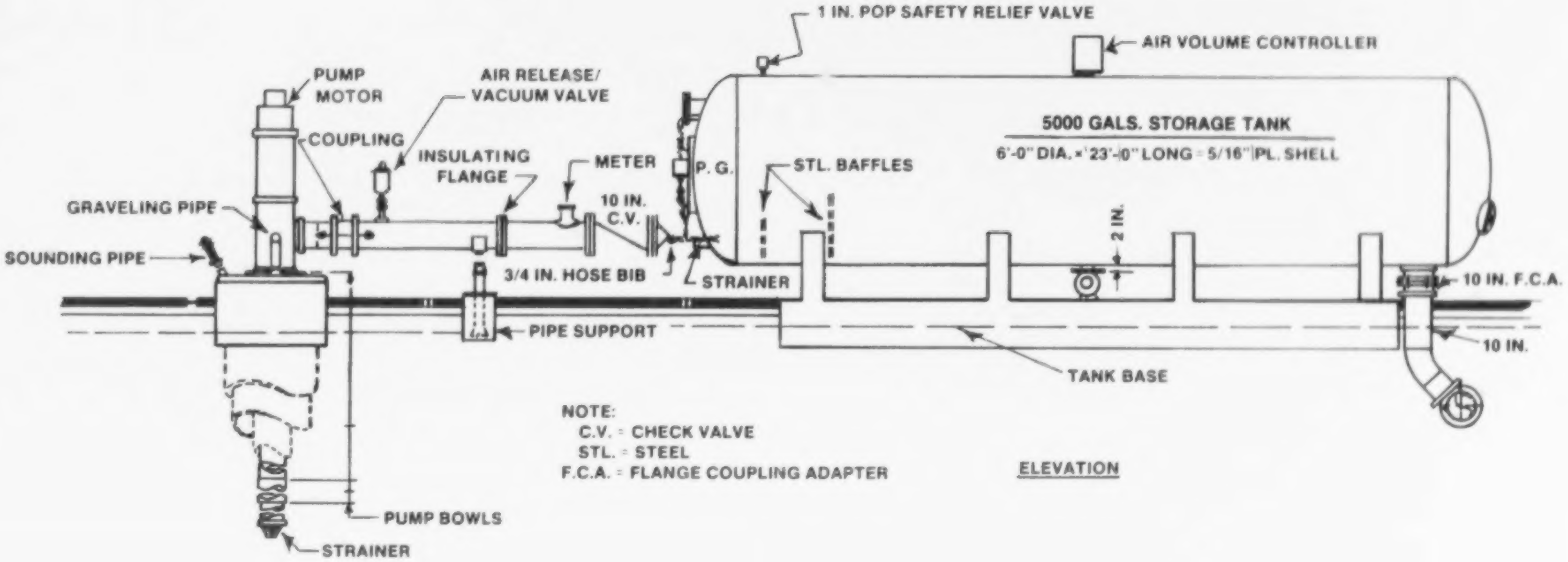
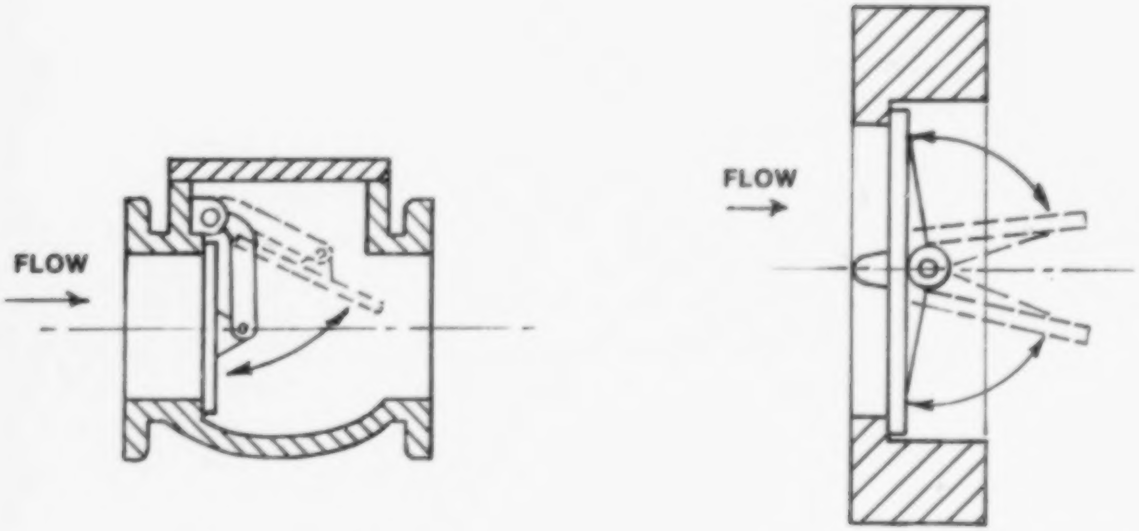

1 IN. POP SAFETY RELIEF VALVE
AIR VOLUME CONTROLLER
PUMP MOTOR
AIR RELEASE/ VACUUM VALVE
COUPLING
INSULATING FLANGE
METER
5000 GALS. STORAGE TANK
6'-0" DIA. × 23'-0" LONG = 5/16" PL. SHELL
P. G.
STL. BAFFLES
10 IN. C.V.
GRAVELING PIPE
2 IN.
SOUNDING PIPE
3/4 IN. HOSE BIB
STRAINER
10 IN. F.C.A.
PIPE SUPPORT
10 IN.
TANK BASE
NOTE:
C.V. = CHECK VALVE
STL. = STEEL
F.C.A. = FLANGE COUPLING ADAPTER
ELEVATION
PUMP BOWLS
STRAINER

Fig. 3.4 Typical well pump and appurtenance installation

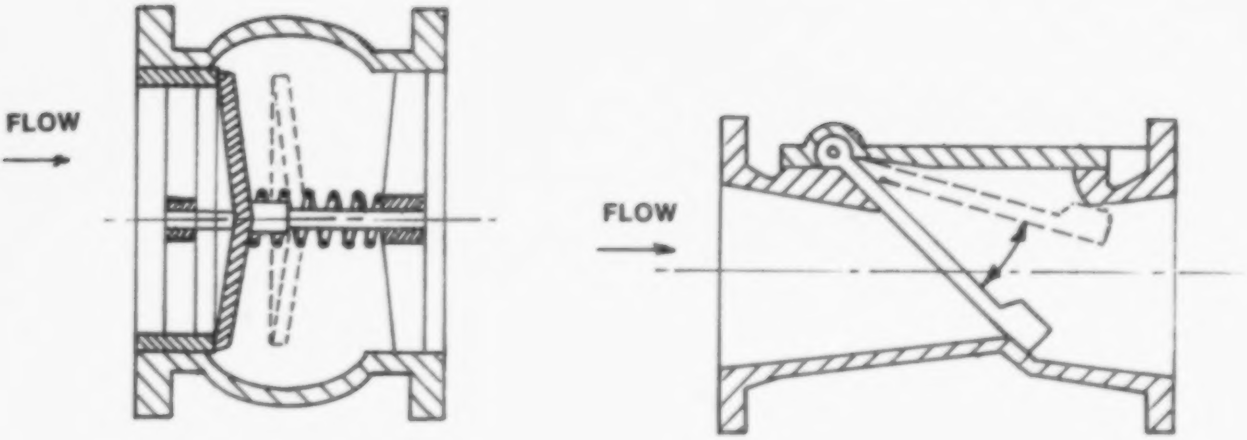
73

73



1. SWING CHECK

2. DOUBLE DISC. CHECK



3. GLOBE CHECK

4. SLANTING DISC CHECK

NOTE: ALL VALVES ARE IN THE CLOSED POSITION.
THE DASHED LINES SHOW THE OPEN POSITION.

Fig. 3.5 Types of check valves

stopping of deep well pumps. This valve is available in a "normally closed" type, or a "normally open" type.

The "normally closed" type valve is designed for installation in the main discharge line of the pump. The pump starts against a closed valve. When it is started, the *SOLENOID*[21] control valve is energized and the valve begins to open slowly, gradually increasing line pressure to full pumping head. When the pump is signalled to shut off, the solenoid control valve is de-energized and the valve begins to close slowly, gradually reducing flow while the pump continues to run. When the valve is closed, a limit switch assembly, which serves as an electrical interlock between the valve and the pump, releases the pump starter and the pump stops. Should a power failure occur, a built-in lift-type check valve closes the moment flow stops, preventing reverse flow regardless of solenoid or diaphragm assembly position.

The "normally open" type valve is designed for installation in a by-pass line on the discharge side of the pump. Operation is completely automatic, fully hydraulic, and electrically controlled by a solenoid control valve. With the pump off, the valve is wide open. When the pump is started, the solenoid is energized and the valve begins to close slowly, discharging air and the initial rush of water and any sand from the pump column to the atmosphere. As the check valve closes, the pump output is gradually diverted into the main line as the main line check valve opens, thus preventing the development of starting surges.

When it is time to shut off the pump, the solenoid is de-energized. A limit-switch on the valve keeps the pump motor circuit closed (power stays on). The pump continues to run while the pump control valve opens slowly and diverts pump output to atmosphere. As pump pressure gradually decreases, the main line check valve closes slowly, effectively preventing shock or slam during the pump stopping cycle. When the pump control valve is wide open, the limit-switch assembly breaks the pump motor circuit and the pump stops.

Both the normally closed and normally open pump control valves are hydraulically operated, diaphragm-type globe or angle valves powered by line pressure. While somewhat different in installation and operation, the purpose of both is much the same. They eliminate line surge when the pump is started and stopped. Both valves are electrically interlocked to the pump motor so that the valve is gradually opened or closed in coordination with the pump, thus protecting the line from uncontrolled surge.

3.212 Foot Valves

A foot valve is often placed at the inlet to the pump suction line in a well. The foot valve can serve several important purposes:

1. Maintains the *PRIME*[22] on the pump,
2. Prevents reversal of flow into the well when the pump shuts off which could stir up sand, and
3. Eliminates problems created when there is no means of discharging air in the pump column and the air enters the system.

3.22 Flow Meters

Good waterworks practice requires you to know the amount of water being delivered to the system. If chemicals are being applied at the well pumping station, then it is necessary to know the rate at which water is being pumped to the system in order to calculate the correct feed rate. A flow meter is used to measure this flow. Well pumps are usually designed for a certain rated capacity (flow rate) pumping against a specified head (system pressure). Since the system pressure against which a well pump must operate changes with system demand (usage), the amount of water delivered to the system usually deviates from the rated capacity given for the pump. Thus, a 1,000 gallon per minute (5,540 cu m/day) pump is supposed to deliver, under normal conditions of specified head and pipe friction, 1,000 gallons of water per minute to the discharge end of the pump. Since this ideal condition is seldom experienced in actual operation, the rated capacity of the pump is not an accurate measurement of the water delivered. Flow meters are used to determine the amount of water actually being delivered by the pump.

Many different types of flow meters are available today such as positive displacement, propeller, turbine, orifice plate, and electronic sensor types. The most commonly used flow meter for well pump applications is the propeller or turbine type, with magnetic drive, equipped with a register for total flow and a rate of flow indicator. This type of flow meter has an accuracy of plus or minus 2 percent of actual flow within a specified range. Accessory features include remote indicator/totalizer plus an onsite strip recorder. In variable-flow well pump installations, this type of meter can be equipped to pace (regulate) auxiliary chemical feeders or chlorinators.

Questions

Write your answers in a notebook and then compare your answers with those on page 116.

3.2A What is the purpose of a check valve?

3.2B List the important features of a check valve.

3.2C What is the purpose of pump control valves?

3.2D Why must flows be known when chemicals are being applied at a well pumping station?

3.23 Sand Traps and Sand Separators

Sand particles should be prevented from entering the distribution system. Nearly all wells produce some sand and tests have shown it is the sand particles larger than 200 *MESH*[23] (74 microns) that cause the most trouble in a distribution system. Almost all sand found in well water is this size or coarser. These particles can cause reduced pump efficiencies due to worn impellers, sanded water mains, excessive meter wear and plugging, wearing of household plumbing fixtures and appliances, and customer complaints.

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[21] *Solenoid (SO-luh-noid). A magnetically (electrical coil) operated mechanical device. Solenoids can be a small valve or a switch.*

[22] *Prime. The action of filling a pump casing with water to remove the air. Most pumps must be primed before startup or they will not pump any water.*

[23] *Mesh. One of the openings or spaces in a screen or woven fabric. The value of the mesh is usually given as the number of openings per inch. This value does not consider the diameter of the wire or fabric; therefore, the mesh number does not always have a definite relationship to the size of the hole.*

3.230 Sand Traps

Conventional sand traps usually consist of a large tank equipped with a series of internal baffles or chambers. The tank is mounted on the discharge side of the well pump. Sand particles settle to the bottom of the tank by the force of gravity and are removed by means of blow-off valves or underdrain systems. *HYDROPNEUMATIC*[24] pressure tanks are sometimes modified with internal baffles and can function, to a limited degree, as a sand trap. Generally speaking, sand traps are costly and inefficient.

3.231 Sand Separators

Most sand separators are designed around the principle of centrifugal force and are relatively effective in removing fine sand, scale, and similar materials from the water.

The centrifugal sand separator is a specifically designed hydraulic centrifuge operating on energy supplied by the well pump. Take a close look at Figure 3.6 as you read about how the separator works. Sand-laden water enters the cylindrical chamber through the feed entry. Inside the chamber the water flows in a circular motion around the outside of the cylinder. As the water spirals inward toward the entrance to the cleaned water exit pipe, extremely high forces act on the sand particles to rapidly force them toward the wall of the cylinder. Once the sand particles reach the cylinder wall, they progress by a downward spiraling action toward the tip of the truncated cone and are finally discharged through an *ORIFICE*[25] (slit in cone) into the accumulator tank, or underflow chamber. Sand is periodically drained from the accumulator tank or chamber by either manual or automatic means. Centrifugal sand separators are usually capable of removing 95 percent of the plus 200 mesh sand particles entering the unit.

Sanitary hazards associated with sand separators or sand traps are generally limited to the discharge system from the accumulator tank. Typically, the sand/water mixture from the accumulator tank is discharged to a sand recovery basin where the sand particles settle out and the sand-free water is disposed of to the community storm sewer or sanitary sewer main. To provide the necessary backflow protection, an *AIR GAP*[26] is required on the discharge line between the accumulator tank and the sand disposal basin or structure. Backflow protection is usually not required if the discharge line from the accumulator has a free discharge to the atmosphere and ends at least 12 inches (300 mm) above the surrounding ground elevation.

For additional information on how to solve problems caused by sand, see Section 3.7, "Sand in Well Water Systems."

3.24 Tank Coatings

Steel water storage tanks and hydropneumatic pressure tanks are generally painted on the interior surface with some type of protective coating to extend the useful life of the tank, prevent discolored water from entering the distribution system, and to facilitate in the cleaning of the tank.

Numerous interior tank coating materials are currently available. Many of these coatings give excellent results if the metal surfaces are properly prepared, the proper material for the job is selected, the material is applied according to the manufacturer's specifications, and it is allowed to dry thoroughly between coats and after the final coat. Adequate curing time is essential with all types of coatings and may require special techniques (such as forced ventilation and extended drying time) to insure that *VOLATILES*[27] have been dissipated from the coating.

Before applying any coating, the water system operator must verify that the selected paint, lining, coating, thinners and conditioners contain no toxic ingredients which might contaminate the water in the tank. The American Water Works Association has developed an excellent standard for outside and inside paint systems for tanks titled A.W.W.A. D102.

Questions

Write your answers in a notebook and then compare your answers with those on page 116.

3.2E Why should sand particles be prevented from entering the distribution system?

3.2F Why are sand traps not recommended for the removal of sand from well water?

3.2G What types of materials may be removed from water by a sand separator?

3.2H Why are steel water storage tanks and hydropneumatic pressure tanks painted on the interior surface with some type of protective coating?

3.2I What sanitary hazards are associated with sand traps or sand separators?

---

[24] *Hydropneumatic (HI-dro-new-MAT-ick). A water system, usually small, in which a water pump is automatically controlled (started and stopped) by the air pressure in a compressed-air tank.*

[25] *Orifice (OR-uh-fiss). An opening (hole) in a plate, wall or partition.*

[26] *Air Gap. An open vertical drop, or vertical empty space, that separates a drinking (potable) water supply to be protected from another water system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because there is no way raw water or any other water can reach the drinking water.*

[27] *Volatile (VOL-uh-tull). A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.*

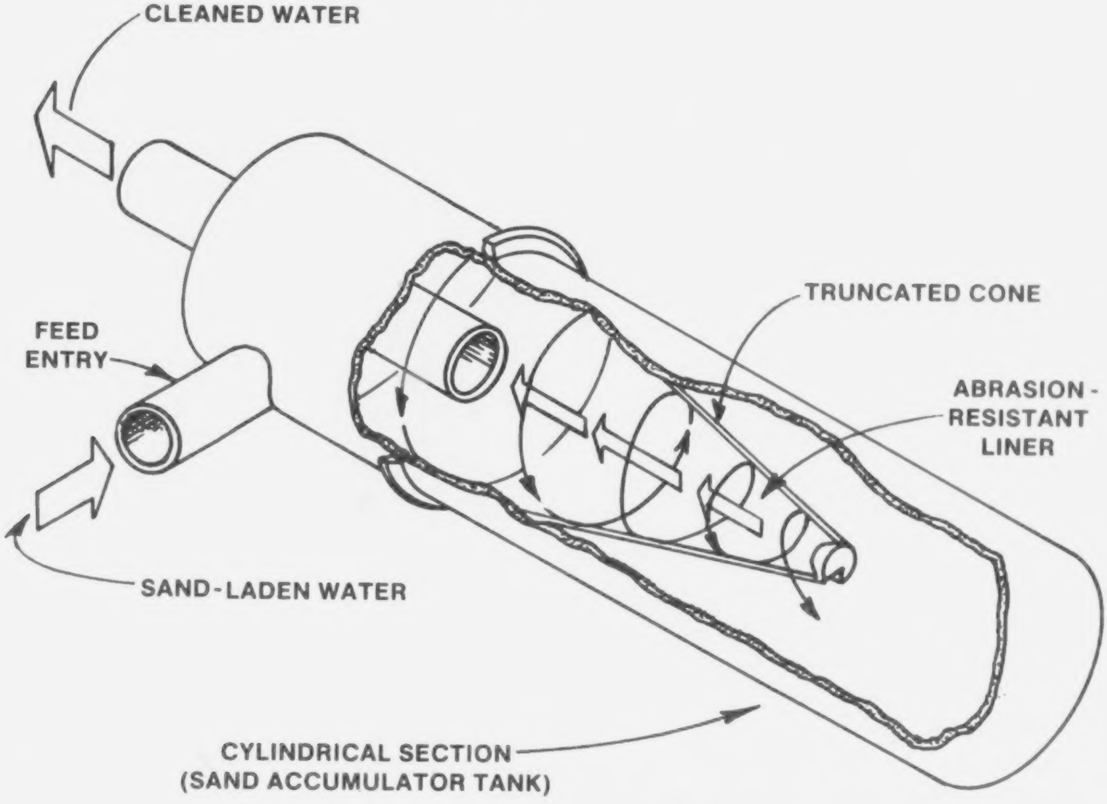

Fig. 3.6 Typical sand separator

3.25 Surge Suppressors

In certain situations a booster pump is used in conjunction with the main well pump. This type of operation usually involves pumping a small amount of water to a specific pressure zone in the distribution system that operates at a much higher pressure or higher elevation than the main well pump system.

Frequent start-stop operation of the booster pump, combined with the higher system pressure, could create problems such as pulsation, vibration, and possible damage to the piping network. To correct this problem, surge suppressors are sometimes installed on the discharge side of the booster pump. Their function is to absorb shock waves in the fluid (water) system and prevent their transmittal through the line.

One relatively simple surge suppressor design consists of a flexible, fully enclosed rubber bladder or diaphragm mounted within a steel shell and connected to the piping system with flanged fittings. The upper chamber is filled with air or nitrogen gas. When a surge occurs, flow from the main system line enters the surge suppressor through a specially designed metering port where a portion of the *KINETIC ENERGY*[28] is dispelled. The dampened pressure surge then continues into the lower fluid chamber where the remaining kinetic energy is dissipated by compressing the air or gas in the upper pressurized chamber. When the compressed air or gas expands forcing the fluid back into the main system, more residual kinetic energy is lost in the controlled flow back through the metering port.

Hydropneumatic tanks also serve as surge suppressors and can be used in a direct line of flow mode or connected to the booster pump discharge line by means of a tee fitting.

3.26 Air and Vacuum Valves

An air and vacuum valve, commonly referred to as an air release/vacuum breaker valve, has a large venting orifice and is used to exhaust large quantities of air very rapidly from a deep well pump column when the pump is started. After the air has been exhausted from the pump column, the valve closes and remains closed. When the pump stops, the valve will immediately open to allow air to re-enter the pump column and prevent a vacuum from developing.

The orifice of the valve must be equipped with an approved vent assembly consisting of a downturned screened opening mounted at least 12 inches (300 mm) above the finished surface of the well lot or above any anticipated high water (flood) level. The open end of the vent must be equipped with holes or fine mesh screen to keep insects out of the well.

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[28] *Kinetic Energy. Energy possessed by a moving body of matter, such as water, as a result of its motion.*

The valve should be properly sized (usually a minimum of 2 inches (50 mm)) to allow the unrestricted flow of air into and out of the pump column. Improperly sized or poorly constructed vents could cause the well pump base gasket or sealing material to be blown out on pump startup. This in turn could allow insects and foreign debris to be sucked back down into the well when the pump stops.

3.27 Pressure Relief Valves

Pressure relief valves should be installed on all hydropneumatic tanks. Excessive internal pressures (surge pressures), often referred to as *WATER HAMMER*,[29] could cause the tank to explode or rupture. A typical pressure relief valve is illustrated in Figure 3.7.

Water hammer is frequently encountered in water supply and treatment facilities. Water hammer may be caused by the quick opening or closing of valves such as fire hydrant valves, the startup or shutdown of pumps, and other conditions that could cause a pulsation of pressures above and below the operating pressure, and a rapid acceleration or deceleration of the velocity of flow. The increased pressure may be several times the normal operating pressure, which can seriously damage hydropneumatic tanks, valves, and the piping network.

Water hammer can be controlled or eliminated by using pressure relief valves. These automatic valves have a spring tension pre-set to a certain operating pressure. In the case of well pump installations, the valve is usually set at 125 pounds per square inch (862 k Pa or 8.8 kg/sq cm). Pressure in excess of this setting will open the valve, allowing air or water to escape and preventing an excess pressure buildup.

3.28 Air Chargers

3.280 Methods of Air Charging

Several methods are available for adding air to a hydropneumatic tank. *ONE METHOD* is to use the air in the well pump column. Instead of discharging the air in the column to atmosphere when the pump starts, the column of air is forced into the tank. With this method, the tank must be equipped with an air release valve and a riser pipe extending down to the midpoint of the tank. The riser pipe is designed to maintain an approximate 50:50 air:water ratio in the tank. This method should be used with caution due to the possibility that during periods when the well pump is cycling on/off at a frequent rate, excess air may not be discharged fast enough through the air release valve and the tank may become air logged (contain too much air). If this occurs, air could be pumped out into the distribution system with resultant problems and consumer complaints.

A *SECOND METHOD* of air charging a tank is to manually add air to the tank on an "as needed" basis by means of a portable air compressor. This technique can be very time consuming and costly.

The *MOST SATISFACTORY METHOD* is to automatically add air by means of an on-site, permanent, air-charging device. Two general types are currently available: the hydraulic principle type and the motor-driven air compressor type.

3.281 Hydraulic Principle Air Charger (Figure 3.8)

The hydraulic principle air charger uses the water pressure of the tank to force air into the tank. The unit normally mounts vertically on one end of a horziontal pressure tank. This unit consists of a closed cylindrical tube section, an upper and lower float, a pilot valve, a one-way air valve, plus a water supply line with sand strainer connected near the bottom of the tank, and an air discharge line connected to the top of the tank.

The unit adds air to the tank on the upward compression stroke and releases water on the downward exhaust stroke. The unit continues to cycle until the preset air-to-water ratio is reached. Approximately 2⅔ gallons (10 liters) of water is discharged from the unit during each complete cycle. The drain line from this unit should not be directly connected to a sewer line. An air-gap separation is recommended to protect the tank from backsiphonage.

3.282 Air Compressor Air Charger (Figure 3.9)

This type of air charger is composed of three primary elements: the air compressor, the liquid level switch, and the pressure switch. The liquid level switch senses the water level in the tank via an electrode suspended into the tank. When the water level in the tank exceeds the preset level, the liquid level switch starts the compressor and air is pumped into the tank. The compressor runs until either the pressure rises sufficiently to open the unit's pressure switch or the water level descends below the preset level.

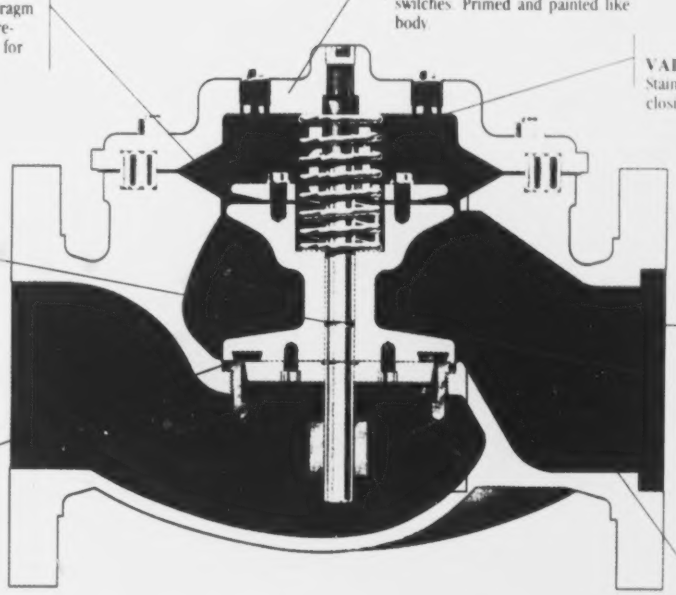
The unit mounts directly on top of the hydropneumatic tank and is protected by means of a weather proof cover. No drain lines are required and the air entering the compressor is filtered.

The two types of air chargers require routine maintenance and have not been trouble-free. However, the desirability and advantages of automatically maintaining the proper air-to-water ratio in a hydropneumatic tank far offset the operational problems of these two types of air charging devices.

Routine maintenance on the hydraulic principle air charger consists of draining the "Y" pattern sand strainer on the inlet line on an "as needed" basis, and maintaining the freeze-protection equipment if mounted outdoors.

---

[29] *Water Hammer. The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.*



DIAPHRAGM
Separates upper chamber operating pressure from low chamber line pressure. Buna-N diaphragm standard; Viton available if required; all Nylon reinforced for high strength and long life.

BONNET
Four tapped ports for pilot piping. Center port for valve position indicator or valve actuated switches. Primed and painted like body.

VALVE SPRING
Stainless steel spring aids in closing the valve.

O-RING
Creates a static seal. No packing glands required, therefore breakaway friction is eliminated and valve will operate even at extremely low pressures.

DIAPHRAGM ASSEMBLY
The only moving part of the Model 65 valve. Ductile iron spool, seat retainer, diaphragm plate. Guided top and bottom by bronze or Teflon bushings.

VALVE SEAT
Buna-N or Viton compensates for wear on seating surface and maintains a drip-tight seal over extended service life.

BODY
Globe pattern 1-1/4 — 12", 250 lb. iron, 150 & 300 lb. steel, 150 lb. aluminum. Screwed ends 1-1/4 — 3" globe & angle. Iron & steel bodies epoxy primed inside and out with baked enamel exterior. Four tapped ports for pilot piping.

SEAT RING
Bronze or stainless steel ring is replaceable and provides a lower guide for the stainless steel valve stem.

NOTE:
Basic valve can be used as a pressure, relief, altitude control or pressure reducing valve depending on type of "brains" piped to valve.

BASIC VALVE

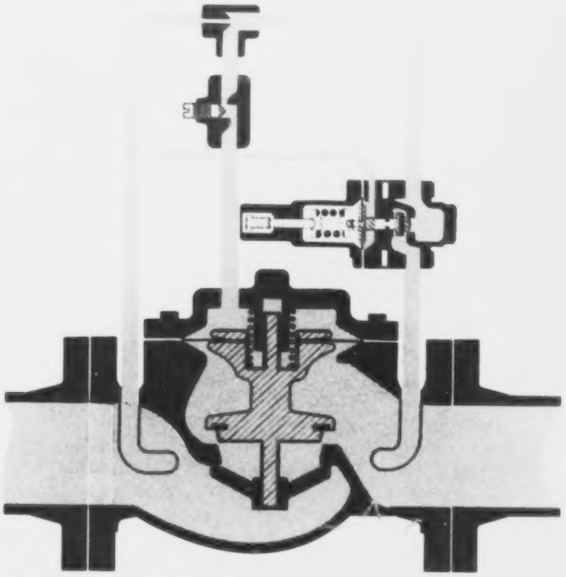


Fig. 3.7 Pressure relief valve
(Permission of OCV Control Valves)

Routine maintenance on the air compressor air charger consists of lubrication, cleaning the filter element on the compressor air inlet on an "as needed" basis, and maintaining the correct tension on the compressor belts. Set up a maintenance program based on the specific type of facilities that you are working with. Use the manufacturers' bulletins and maintenance procedures as guidelines.

3.29 Hydropneumatic Pressure Tank Systems

3.290 Applications

Hydropneumatic pressure tank systems can be used very successfully in well pump operations to maintain adequate pressure throughout distribution systems. In areas where the topography is generally flat, hydropneumatic systems are quite common. They can be used for small water systems with one or two wells; for larger water systems with many wells strategically located in a grid system; or to supply service to isolated areas. Hydropneumatic pressure tank systems can also be integrated with gravity storage systems, although this is not a widespread practice.

3.291 Tank Size

Hydropneumatic tanks range in capacity from 40-gallon (150 liters) tanks serving single families to 21,000-gallon (80,000 liters) or larger size tanks for public water systems. The tank size will depend upon many factors such as geographic location, pump capacity, peak demand, pump cycling rate, economics, past operational experience, and the amount of property available to the water supplier for plant facilities.

3.292 Operation

When hydropneumatic pressure tank systems are designed, the best operating pressure differential, the control levels in the tank, the pumping differential and the tank efficiency, and the tank size are determined by the designer. This information and procedures for any necessary adjustments should be provided in the operation and maintenance instructions for the system.

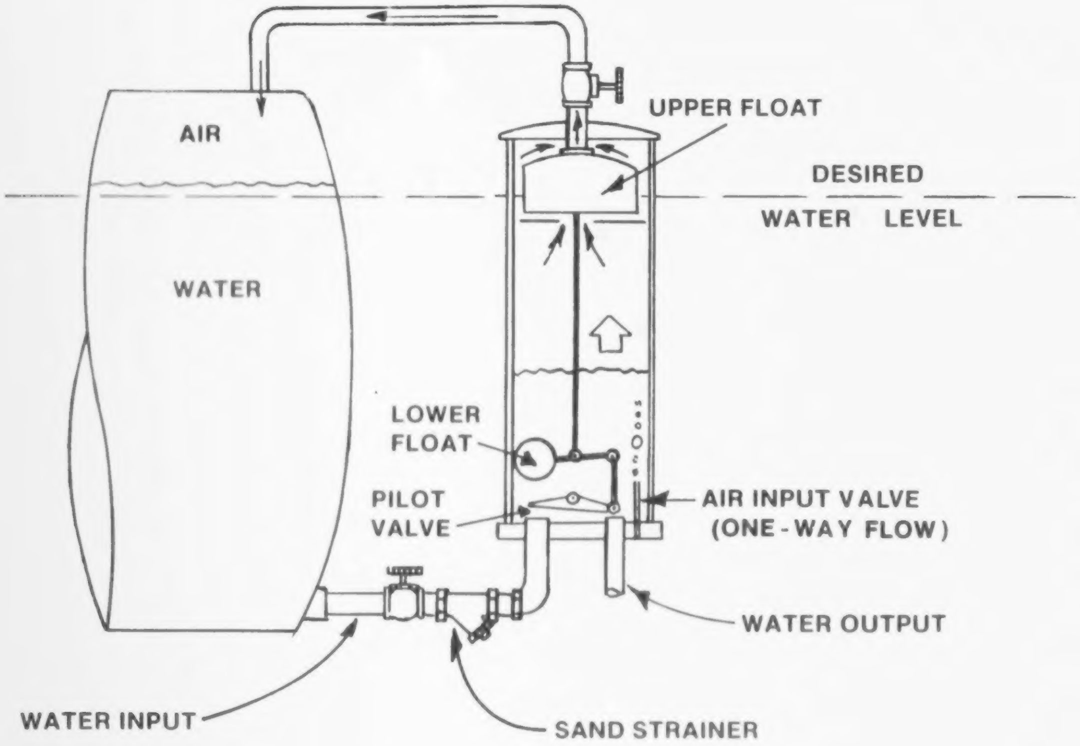


Fig. 3.8 Typical hydraulic air charger

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 116.

3.2J Under what circumstances might a booster pump be installed?

3.2K What is the purpose of surge suppressors that are sometimes installed on the discharge side of a booster pump?

3.2L What is the purpose of an air release/vacuum breaker valve?

3.2M Why are pressure relief valves installed on hydropneumatic tanks?

3.2N What is the purpose of an air charger?

3.2O The size of a hydropneumatic tank is influenced by what factors?

3.3 WELL MAINTENANCE AND REHABILITATION

3.30 Importance of Well Maintenance

If the well casing, well screen, filtering material and other appurtenances of a well are properly designed and correctly installed by a qualified well driller, maintenance of a well will be minimized. However, wells, like all other waterworks facilities, need periodic routine maintenance in the interest of a continuous high level of performance and a maximum useful life. The usual attitude towards maintenance of wells is "out of sight — out of mind." Consequently, very little or no attention is paid to wells until problems reach crisis levels, often resulting in the complete loss of the well. The importance of a routine maintenance program for the prevention, early detection and correction of problems that reduce well performance and useful life cannot be over emphasized. A maintenance program can pay handsome dividends to a well owner and will certainly result in long-term benefits that exceed the cost of implementation and continuation of the program.

3.31 Factors Affecting the Maintenance of Well Performance

3.310 Adverse Conditions

The factors affecting the maintenance of well performance or yield are numerous. Care should be taken to distinguish between factors associated with the normal wearing of pump parts and those directly associated with changing conditions in and around the well. A perfectly functioning well, for example, can show a reduced yield because of a reduction in the capacity of the pump due to excessively worn parts. On the other hand, the excessive wearing of pump parts may be due to the pumping of sand that entered the well through a corroded well screen. Corrosion may reduce the pump capacity but, at the same time have little or no effect on a properly designed well. There will be some overlap in what is called well maintenance and what is called pump maintenance. Conditions (which we'll consider well maintenance problems) that should be guarded against are overpumping and lowering of the water table, clogging or

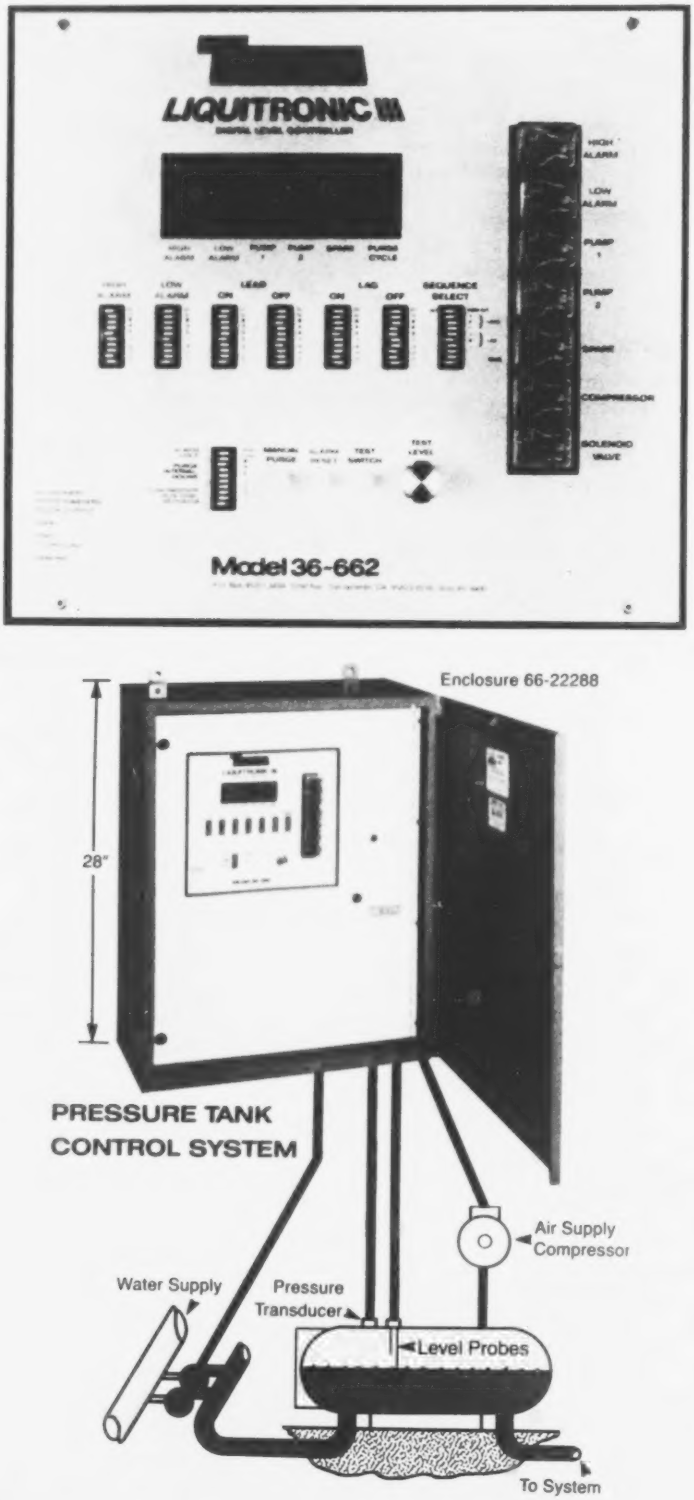

LIQUITRONIC III
DIGITAL LEVEL CONTROLLER
HIGH ALARM
LOW ALARM
PUMP 1
PUMP 2
SPARE
PURGE CYCLE
LEAD
ON
OFF
LAG
SEQUENCE SELECT
MANUAL PURGE
ALARM RESET
TEST SWITCH
TEST LEVEL
COMPRESSOR
SOLENOID VALVE
Model 36-662
Enclosure 66-22288
28"
PRESSURE TANK
CONTROL SYSTEM
Air Supply Compressor
Water Supply
Pressure Transducer
Level Probes
To System

Fig. 3.9 Air compressor air charger
(Permission of TESCO, Sacramento, CA)

collapse of a screen or perforation section, and corrosion or incrustation.

3.311 Overpumping

Overpumping was discussed in Section 3.001, "Overdraft," so we'll only summarize the problems here. Overpumping an aquifier can damage the well by reducing the storage and production capacity of groundwater systems. The net result is consolidation of the water-bearing formations which provides less storage space, a lowering of the water table and a reduced yield from the well. Other problems that may develop from overpumping or installing the pump section too high include pumping air and also water cascading into the well. The well production rate is normally determined by the well driller and hydrogeologist at the time the well is drilled and developed.

3.312 Clogging or Collapse of Screen

A decrease in the capacity of a well most commonly results from clogging of the well screen openings and the water-bearing formation immediately around the well screen by incrusting deposits. These incrusting deposits may be of the hard cement-like form typical of the carbonate and sulfate compounds of calcium and magnesium, the soft sludge-like forms of the iron and manganese hydroxides, or the gelatinous slimes of iron bacteria. Iron may also be deposited in the form of ferric oxide with a reddish-brown, scale-like appearance. Less common is the deposit of soil materials such as silt and clay. More will be said about incrustation later.

Well screens are designed to fit individual well formations and are composed of numerous slits as shown on Figure 3.10. As can be seen from this figure, if the slits in the casing become incrusted and blocked, the available area for water to move through is severely limited. If corrosion should occur, the slits may enlarge enough for grit and sand to be carried into the well along with water. This, in turn, will damage the pump and appurtenances. If the corrosion is severe enough, total collapse of the screen could occur.

3.313 Corrosion or Incrustation

Corrosion is a process which results in the gradual decomposition or destruction of metals. Corrosive waters are usually acid and may contain relatively high concentrations of dissolved oxygen which is often necessary for and increases the rate of corrosion. High concentrations of carbon dioxide, total dissolved solids and hydrogen sulfide (with its characteristic odor of rotten eggs) are other indications of a possibly corrosive water.

Besides water quality, there are other factors such as velocity of flow and dissimilarity of metals which contribute to the corrosion process. The greater the velocity of flow, the greater is the removal of the protective corrosion end products from the surface of the metal and hence the exposure of that surface to further corrosion. This is another important reason for keeping the velocity through screen openings within acceptable limits. The use of two or more different types of metals such as stainless steel and ordinary steel, or steel and brass or bronze should be avoided whenever possible. Corrosion is usually greatest at the points of contact of the different metals or where they come closest to contact.

Casing failure by corrosion ruins a well as fast as failure of the screen. Failure can cause the introduction of clay and polluted or otherwise unsatisfactory water into the well. Corrosive well waters have been known to destroy steel casings in less than six months, thus ruining many wells.

Incrustation, unlike corrosion, results not in the destruction of metal, but in the deposition of minerals on the metal and in the aquifer immediately around a well. Physical and chemical changes in the water in the well and the adjacent formation cause dissolved minerals to change to their insoluble states and settle out as deposits. These deposits block the screen openings and the pore spaces immediately around the screen with a resulting reduction in the yield of the well.

Incrusting waters are usually alkaline or the opposite of corrosive waters, which are acid. Excessive carbonate hardness is a common source of incrustation in wells. Scale deposits of calcium carbonate (lime scale) occur in pipes carrying hard waters. Iron and manganese, to a lesser extent, are other common sources of incrustation in wells. Iron causes characteristic reddish-brown deposits while those of manganese are black.

Often associated with iron-containing groundwater are iron bacteria. These minute (tiny) living organisms are not dangerous to health, but, while aiding the deposition of iron, produce accumulations of slimy, jelly-like material which block well screen openings and aquifer pore spaces.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 116.

3.3A List three major well maintenance problems.

3.3B How can overpumping damage a well?

3.3C What kinds of deposits can develop on well screens?

3.3D Why should the use of two or more different types of metals be avoided in a well?

3.3E What is the difference between incrusting and corrosive waters?

3.32 Preventive Maintenance and Repairs

The best possible procedure for a good maintenance program is adequate recordkeeping. This aspect of the operator's responsibility cannot be overemphasized. Regular well depth measurements before and after pumping, flow rates, water quality samples, length of time pumping, and accurate data on pump repairs and causes are a few of the records that should be routine. The records should be kept neatly and in logical order. This collected data will be an invaluable tool in the hands of an engineer, hydrogeologist,

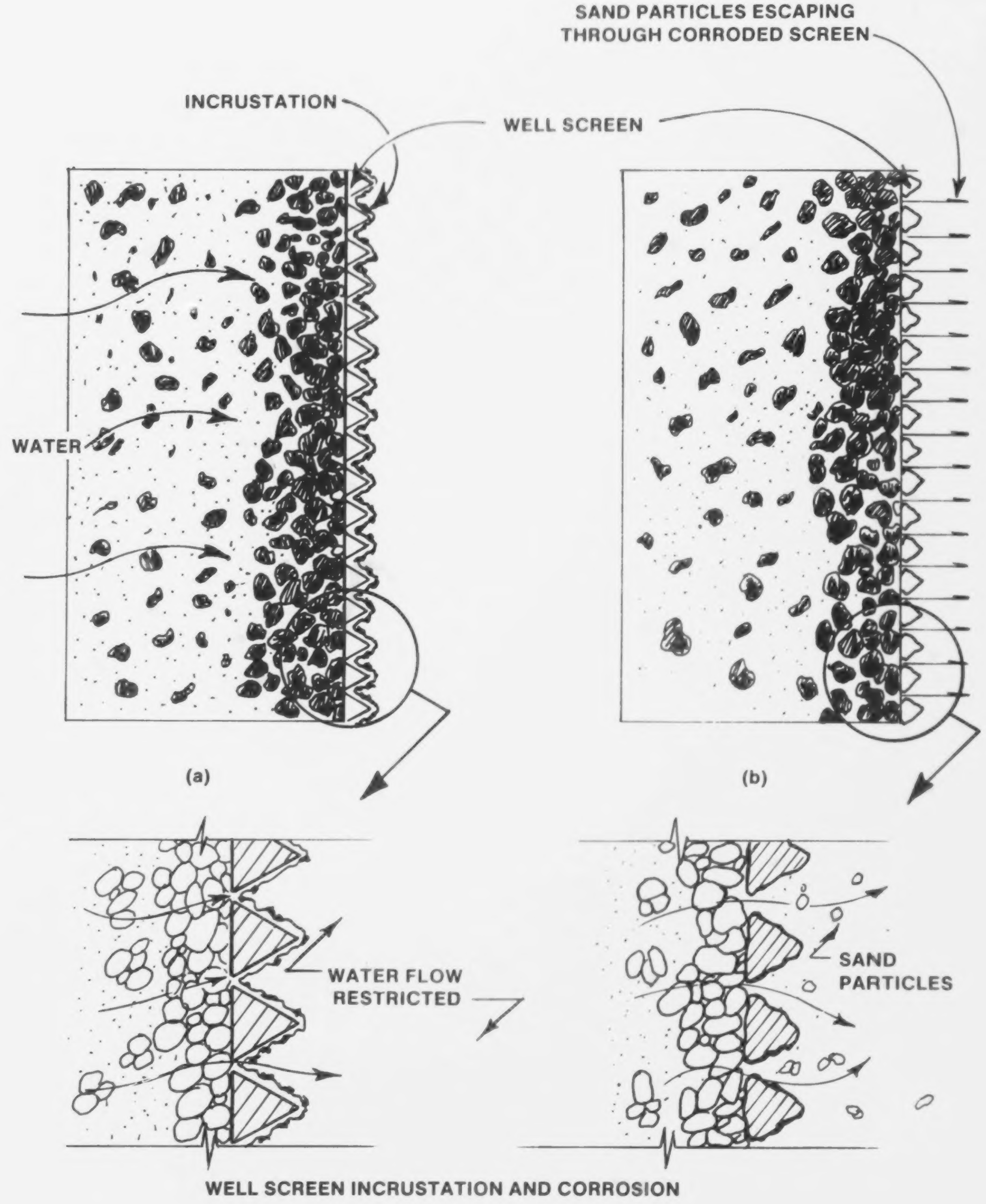

SAND PARTICLES ESCAPING THROUGH CORRODED SCREEN
INCRUSTATION
WELL SCREEN
WATER
(a)
(b)
WATER FLOW RESTRICTED
SAND PARTICLES
WELL SCREEN INCRUSTATION AND CORROSION

Fig. 3.10 Well screen incrustation and corrosion

chemist, or skilled operator. Operators should monitor this data to look for early warnings of such potential problems such as overpumping. In areas where extensive oil and/or gas exploration is being conducted, operators should be alert for changes in water quality which could indicate pollution of an aquifer.

3.33 Casing and Screen Maintenance

The type of materials that go into the well are very important. Wells composed of materials with little or no resistance to corrosion can be destroyed beyond usefulness by a highly corrosive water within a few months of completion. This will be the case no matter how excellent the other aspects of design, construction and maintenance. A poor selection of materials can also result in collapse of the well due to inadequate strength. All these factors have a considerable influence on the useful life of a well.

3.330 Surging

Surging, which is a form of plunging, is a procedure used for opening pores in the screen and for cleaning the gravel pack around the screen. A typical surge arrangement is shown in Figure 3.11

Surging is commonly used for new well development to remove sand from the area around the well screen. However, it is also an effective procedure in combating incrustation when used with acid treatment. Care must be exercised when using surge plungers within the screen area itself and in wells in which aquifers contain large amounts of clay. In cleaning screens, the plunger can become sand-locked by the settling of sand above it. In cleaning the gravel pack around the screen, the action of the plunger can cause the clay to plaster over the screen surface. Plungers should be used only under the supervision of someone experienced in their use.

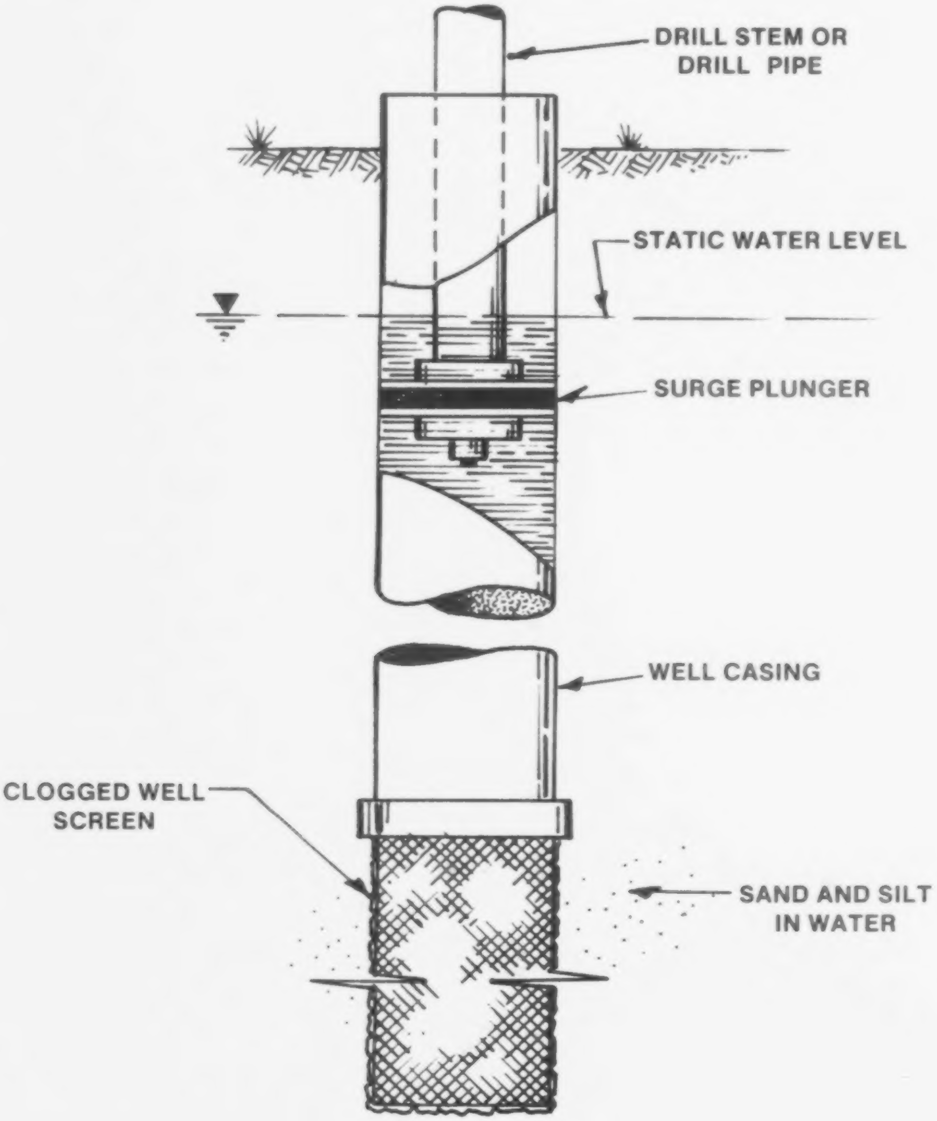


Fig. 3.11 Typical surge plunger arrangement

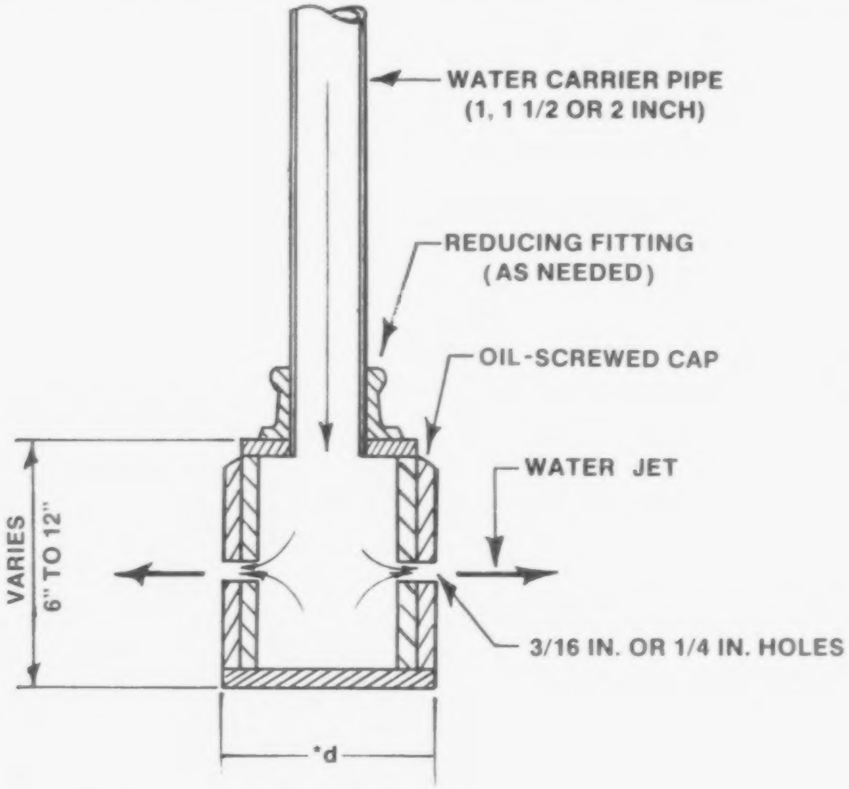
3.331 High-Velocity Jetting

High-velocity jetting is the spraying of water at a high velocity. This is an effective form of backwashing which, when used with acid treatment, is another procedure for removing incrustation from well screens and casings. Jetting can also be used for re-opening the pores of the aquifer and removing sand from the immediate vicinity of the well screen.

A simple form of jetting tool for use in wells is shown in Figure 3.12. An appropriately sized coupling with a steel plate welded over one end is screwed or welded to a pipe. The jetting tool's outside diameter will vary depending on the inside diameter of the well. The maximum and minimum difference in diameter between the jet tool and well screen are two inches (50 mm) and one inch (25 mm) respectively. That is, if the well screen has a ten inch (250 mm) inside diameter, then the jet tool should have an outside diameter between eight and nine inches (200 and 225 mm). Two to four 3/16 or ¼-inch (5 or 6 mm) diameter holes, equally spaced around the circumference, are drilled through the full thicknesses of the coupling and the jetting pipe at a fixed distance along the coupling from the near surface of the steel plate. Better results can be obtained if properly shaped nozzles are used instead of the straight, drilled holes shown in Figure 3.12, but these are also acceptably effective.

The procedure is to lower the tool on the jetting pipe to a point near the bottom of the screen. The upper end of the pipe is connected through a swivel and hose to the discharge end of a high pressure pump such as the mud pump used for hydraulic rotary drilling. The pump should be capable of operating at a pressure of at least 100 pounds per square inch (psi) (690 k Pa or 7 kg/sq cm) and preferably at about 150 psi (1040 k Pa or 10.5 kg/sq cm) while delivering 10 to 12 gallons per minute (GPM) (0.6 to 0.8 *L*/sec) for each 3/16-inch (5 mm) nozzle or 16 to 20 GPM (1.0 to 1.25 *L*/sec) for each ¼-inch (6 mm) nozzle on the tool. For example, a tool with two 3/16-inch (5 mm) diameter nozzles would require a pumping rate of about 20 to 24 GPM (1.25 to 1.5 *L*/sec), while a tool with three ¼-inch (6 mm) diameter nozzles would require a pumping rate of 48 to 60 GPM (3.0 to 3.8 *L*/sec). While pumping water through the nozzles and screen into the formation, the jetting tool is slowly rotated, thus washing and developing the formation near the bottom of the well screen. The jetting tool is then raised at intervals of a few inches and the process repeated until the entire length of screen has been backwashed and fully developed. Where possible, it is very desirable to pump the well at the same time the jetting operation is in progress.

As shown in Figure 3.13, the area of concentration of the spray is very small. Because of this concentration, the jet spraying procedure becomes one of the most effective procedures for screen cleaning and well development.



*d VARIES FROM 1 IN. TO 2 IN. LESS THAN
INSIDE DIAMETER OF WELL SCREEN

Fig. 3.12 Simple jetting tool

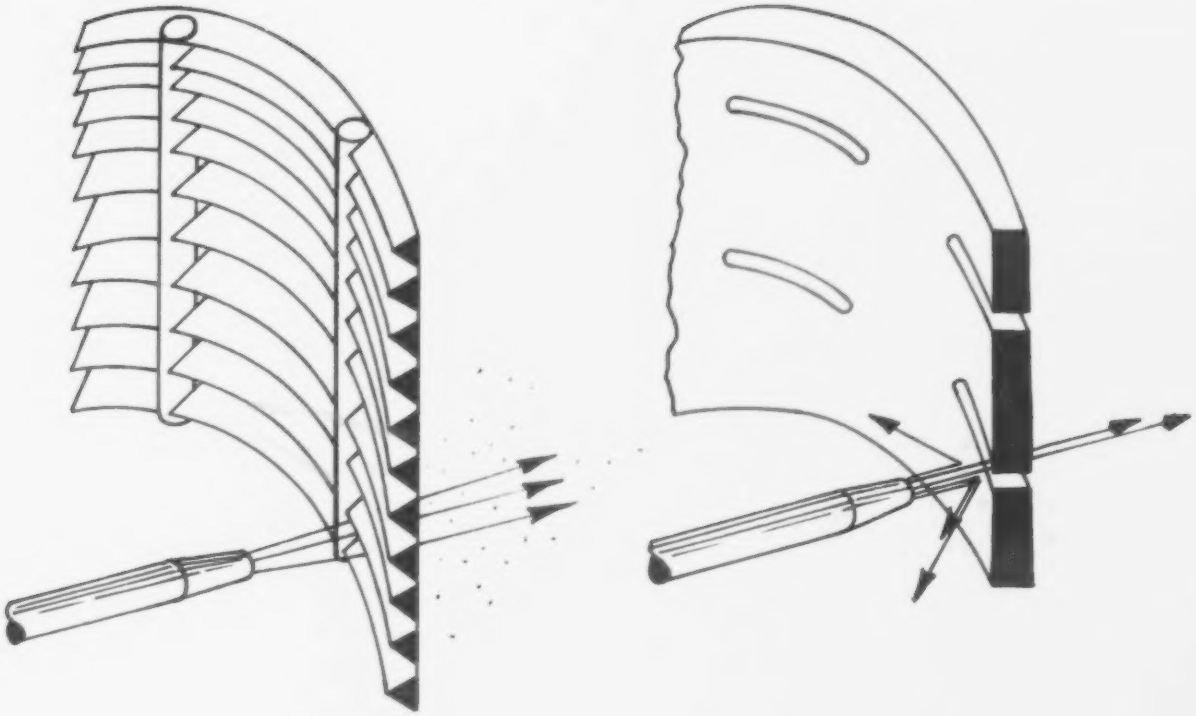


Fig. 3.13 Use of jet spray on well screen

3.332 Acid Treatment

Acid treatment may be the only effective procedure available to loosen incrustation so that it may be removed from the well casing and well. Acids normally used are hydrochloric or sulfamic. Both of these acids readily dissolve calcium and magnesium carbonate, though hydrochloric acid does so at a faster rate. Strong hydrochloric acid solutions also dissolve iron and manganese hydroxides. The simultaneous use of an inhibitor serves to slow up the tendency of the acid to attack steel casing. The use of chemicals in a well requires the proper selection of well materials at the time of construction to avoid damage to the materials by the chemicals.

Hydrochloric acid should be used at full strength. Each treatment usually requires 1½ to 2 times the volume of water in the screen or pipe to be cleaned. This provides enough acid to fill the area to be cleaned and additional acid to maintain adequate strength as the chemical reacts with the incrusting materials. Figure 3.14 illustrates a method of placing acid in a well. Acid can be introduced into the well by means of a wide-mouthed funnel and ¾ or 1-inch (18 or 25 mm) plastic pipe. Acid is heavier than water which it tends to displace but with which it also mixes readily to become diluted.

The acid solution in the well should be agitated by means of a surge plunger or other suitable means for 1 to 2 hours. Following this, the well should be bailed until the water is relatively clear. The driller usually can detect an improvement in the yield of the well while running the bailer. The well may, however, be pumped to determine the extent of improvement. If the results are less than expected, the treatment may be repeated using a longer period of agitation before bailing. Additional treatment may even be undertaken.

The procedure is sometimes varied to alternate acid treatment and chlorine treatment. The chlorine helps to remove the slime deposited by iron bacteria. Sulfamic acid offers a number of advantages over hydrochloric acid as a means of treating incrustation in wells. Sulfamic acid can be added to a well in either its original granular form or as an acid solution mixed on site. Granular sulfamic acid is non-irritating to dry skin and its solution gives off no fumes

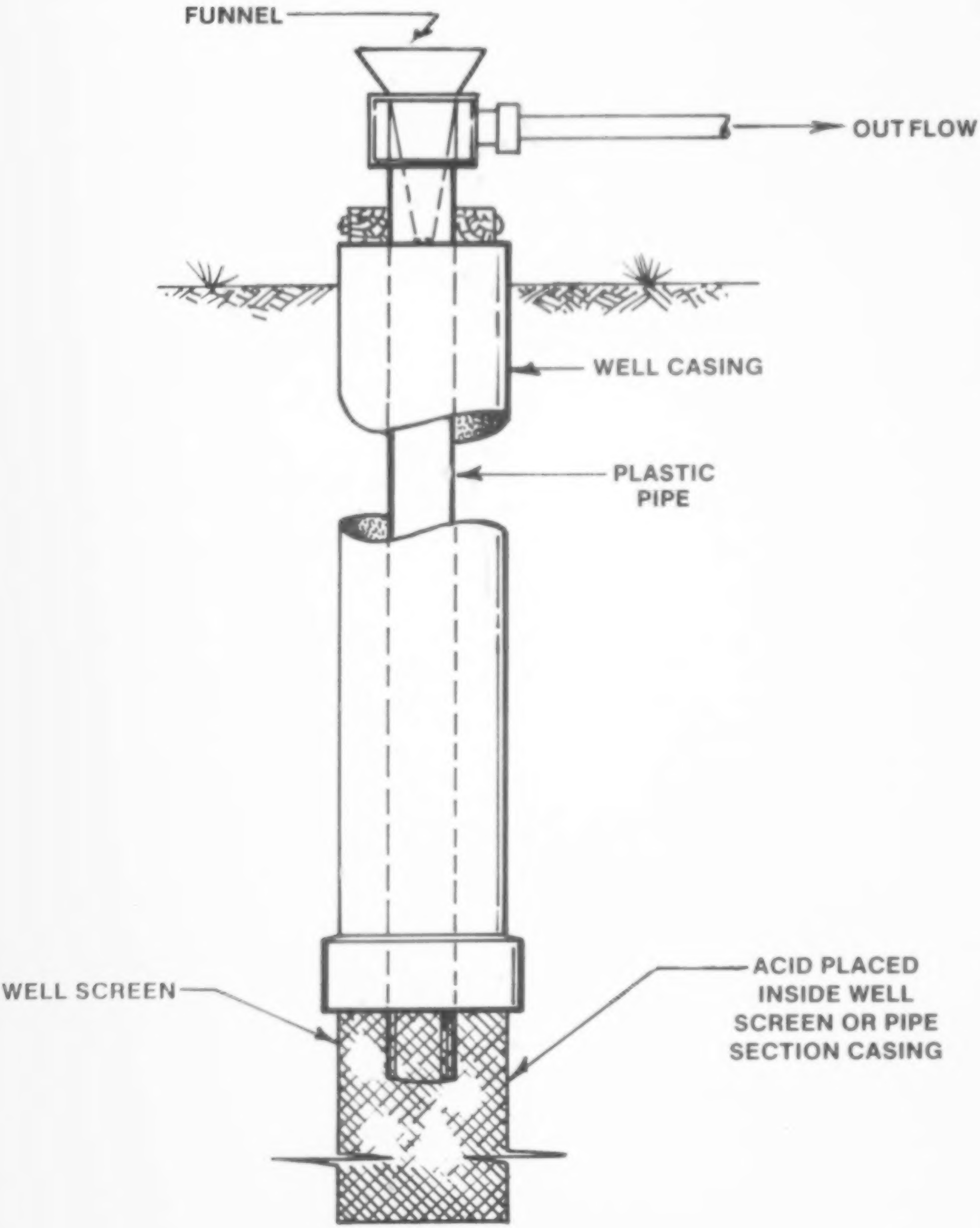

FUNNEL
OUTFLOW
WELL CASING
PLASTIC PIPE
WELL SCREEN
ACID PLACED INSIDE WELL SCREEN OR PIPE SECTION CASING

Fig. 3.14 Procedure for introducing acid into well for purpose of cleaning incrustations from screen and casing

except when reacting with incrusting materials. Spillage, therefore, presents no hazards and handling is easier, cheaper, and safer. Sulfamic acid also has a markedly less corrosive effect on well casing and pumping equipment. Sulfamic acid dissolves calcium and magnesium carbonate compounds to produce very soluble products. The reaction is, however slower than that using hydrochloric acid and a somewhat longer contact period in the well is required. Again, agitation must be provided by some sort of plunger. The quantity of acid added in this case should be based on the total volume of water standing in the well — *NOT* on the volume of just the part of the well to be cleaned (as is the case if the acid is applied in solution form). A little extra granular sulfamic acid may be added to keep the solution up to maximum strength while it is being used up through reaction with the incrusting material. The addition of a low-foaming, non-ionic wetting agent improves the cleansing action to some extent.

A number of precautions must be exercised in using any strong acid solution. Goggles and waterproof gloves should be worn by all persons handling the acid. When preparing an acid solution, *ALWAYS POUR THE ACID SLOWLY INTO THE WATER.* In view of the variety of gases, some of them very toxic, produced by the reaction of acid with incrusting materials, adequate ventilation must be provided in pump houses or other confined spaces around treated wells. Do not allow personnel to stand in a pit or depression around the well during treatment because some of the toxic gases (such as hydrogen sulfide) are heavier than air and will tend to settle in the lowest areas. After a well has been treated, it should be pumped to waste to ensure the complete removal of all acid (measure pH) before it is returned to normal service.

3.333 Chlorine Treatment

Chlorine treatment of wells is more effective than acid treatment in loosening bacterial growths and slime deposits which often accompany the deposition of iron oxide. Because of the very high concentrations required, 100 to 200 mg/L of *AVAILABLE CHLORINE,*[30] the process is often referred to as shock treatment with chlorine. Calcium or sodium hypochlorite may be used as the source of chlorine.

NOTE: Either calcium or sodium hypochlorite can be used. They are *NEVER* used together. Extreme heat or an explosion could occur.

The chlorine solution in the well must be agitated. This may be done by using the high-velocity jetting technique or by surging with a surge plunger or other suitable technique. The recirculation provided with the use of the jetting technique greatly improves the effectiveness of the treatment.

The treatment should be repeated 3 or 4 times in order to reach every part of the formation that may be affected. This treatment may also be alternated with acid treatment, but use the acid first.

3.334 Polyphosphates

Polyphosphates, or glassy phosphates as they are commonly called, effectively disperse silts, clays and the oxides and hydroxides of iron and manganese. The dispersed materials can be easily removed by pumping. In addition, the polyphosphates are safe to handle and are often used in the chemical treatment of wells.

3.335 Explosive Charges

Small explosive charges have been used to clean plugged well screens. Experts in this field should be consulted before attempting this procedure.

3.336 Summary

Although many forms of well cleaning and maintenance have been discussed here, you are cautioned to exercise care in the application of any of these. Always observe manufacturers' recommendations. Obtain expert advice if you are not sure which chemical to use, how to apply the chemical or how to remove it from the well.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 116.

3.3F What records should be kept regarding a well?

3.3G What is the purpose of surging?

3.3H How can the pores in a well screen and the gravel pack around the screen be cleaned?

3.3I How can incrustation be removed from the well casing and well?

3.3J How can bacterial growths and slime deposits be removed from well screens?

3.34 Water Quality Monitoring

Well performance can be affected by the quality of the groundwater. Similarly, water quality, both physical and chemical, is a good indicator of existing or potential problem areas and should be monitored regularly for clues to problems. For example, excessive sand production indicates problems with the well completion procedure and will produce excessive pump wear. The chemical quality of water indicates the type of dissolved minerals in the groundwater and will help in the design of a maintenance program if mineral deposition is suspected to be a cause of decreased well performance.

3.35 Downhole Video Inspection

Downhole video inspection can aid in well maintenance. Cameras take both still photographs and motion pictures of the well with the pumping equipment removed. The tape recorded "video log" of the well can then be reviewed as an aid in designing a maintenance or rehabilitation program. Specific problem areas, such as mineral deposition or other incrustation, corrosion of screen perforations or casing, and mechanical collapse or other failure, can be identified, permitting more precise procedures to correct problems.

3.36 Summary

Maintenance operations should not be put off until problems become serious. When this happens, rehabilitation of a well becomes more difficult and sometimes impossible or impractical. Incrustation not treated early enough can so thoroughly clog the well screen and the formation around it that it becomes extremely difficult (and even impossible) to diffuse or circulate a chemical solution to all affected points in the formation. At this point, any attempts at rehabilitation would most likely prove unsuccessful.

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[30] *Available Chlorine. A measure of the amount of chlorine available in chlorinated lime, hypochlorite compounds, and other materials that are used as a source of chlorine when compared with that of elemental (liquid or gaseous) chlorine.*

No methods have yet been developed for the complete prevention of incrustation in wells. Various steps can be taken to delay the process and reduce the magnitude of its effects. Among these are the proper design of well screens and the reduction of pumping rates, both aimed at reducing entrance velocities into screens and drawdown in wells. For example, it may be worthwhile to share the pumping load among a larger number of wells in order to reduce the rate of incrustation. However, the ultimate or final solution will be in a regular cleaning program. Incrusting wells are usually treated with chemicals which either dissolve the incrusting deposits or loosen them from the surfaces of the well screen and formation materials so that the deposits may be easily removed by bailing. Cork-screw shaped brushes have been rotated in wells to remove encrustations.

Recordkeeping is a must. Only with data on the well's performance can problems be identified or predictions be accurately estimated. A program of recordkeeping should be started when a well is constructed. If such steps were not taken at the time of construction, they should be started as soon as possible.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 116.

3.3K How does the chemical quality of groundwater influence a well maintenance program?

3.3L How can the inside of a well be inspected for incrustation and/or corrosion of a well screen?

End of Lesson 2 of 4 Lessons
on
WELLS

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. WELLS

(Lesson 2 of 4 Lessons)

Write the answers to these questions in your notebook before continuing with Lesson 3. The problem numbering continues from Lesson 1.

6. What could happen when the check valve on a well pump station fails?
7. What is the relationship between system pressure and the flow delivered to the system by a pump?
8. What problems may be caused by sand entering a distribution system?
9. What items would you include in your well maintenance program?
10. What procedures are available for cleaning a well screen?

Chapter 3. WELLS

(Lesson 3 of 4 Lessons)

3.4 WELL PUMPS AND SERVICE GUIDELINES

3.40 Purpose of Well Pumps

3.400 Well Pumps

Once a well is completed and water is available from an aquifer, some type of pump must be installed to lift the water from the well and deliver it to the point of use. The intent of this section is to discuss the general characteristics of well pumps operators are likely to encounter.

Well pumps are generally classified into two basic groups:

1. *POSITIVE DISPLACEMENT* pumps which deliver the same volume or flow of water against any *HEAD*[31] within their operating capacity. Typical types are piston (reciprocating) pumps, and screw or squeeze displacement (diaphragm) pumps; and
2. *VARIABLE DISPLACEMENT* pumps which deliver water with the volume or flow varying inversely with the head (the *GREATER* the head, the *LESS* the volume or flow) against which they are operating. The major types are centrifugal, jet, and air-lift pumps.

Either of these types of pumps can be used for pumping water from a well. However, centrifugal pumps are by far the most commonly used pump in the waterworks field because of their capability to deliver water in large quantities, against high as well as low heads, and with high efficiencies.

3.401 Shallow Well Pump

A pump installed above a well is often called a *SHALLOW WELL PUMP;* this pump takes water from the well by *SUCTION LIFT.*[32] Such a pump can be used for either a deep well or a shallow well providing the pumping level is within the suction lift capability of the pump (maximum of 20-feet (6 m) lift).

3.402 Deep Well Pump

A pump installed in the well with the *PUMP BOWLS*[33] inlet submerged below the pumping level in the well is generally referred to as a *DEEP WELL PUMP.* This type of pump may be used for any well, regardless of depth, where the pumping level is below the limit of suction lift.

3.41 Types of Pumps

3.410 Centrifugal Pumps

A centrifugal pump raises the water by a centrifugal force which is created by a wheel, referred to as an *IMPELLER,* revolving inside a tight *CASING.* In operation, the water enters the pump at the center of the impeller called the *EYE.* The impeller throws the water outwards towards the inside wall of the casing by the centrifugal force resulting from the revolution of the impeller. The water passes through the channel or diffuser vanes between the rim of the impeller and the casing, and emerges at the discharge under pressure. Centrifugal pumps are used almost exclusively in the waterworks field. Advantages of centrifugal pumps include: (1) relatively small space needed for any given capacity, (2) rotary rather than reciprocating motion, (3) adaptability to high speed driving mechanisms such as electric motors and gas engines, (4) low initial cost, (5) simple mechanism, (6) simple operation and repair, and (7) safety against damage from high pressure because of limited maximum pressure that can be developed. Centrifugal pumps are generally classed as *VOLUTE* or *TURBINE* pumps.

3.411 Volute-Type Pumps

This type of centrifugal pump has no diffusion vanes (see Figure 3.15). The impeller is housed in a spiral-shaped case in which the velocity of the water is reduced upon leaving the impeller, with a resultant increase in pressure. Ordinarily, the volute-type pump is of single-stage design and used in the water utility field for large-capacity, low-head application, and for low to mid-range booster pump operations.

3.412 Turbine-Type Pumps

This type of centrifugal pump is the one most commonly used for well pump operations (see Figure 3.16). In the turbine-type pump, the impeller is surrounded by diffuser vanes which provide gradually enlarging passages in which the velocity of the water leaving the impeller is gradually reduced, thus transforming velocity head to pressure head.

Use of multi-stage pumps is standard practice in well pumping operations. The stages are bolted together to form a pump bowl assembly and it is not uncommon to assemble a pump bowl assembly with ten or more stages. The function of each stage is to add pressure head capacity; the volume capacity and efficiency are almost identical for each stage. As an example, in the case of a ten-stage pump rated at 500 gallons per minute (32 liters/sec) at 250 feet (75 m) of required head, utilizing 40 *BRAKE HORSEPOWER*[34] (30 kw), the first stage would pump 500 gallons per minute (32 liters/sec) at 25 feet (7.5 m) of head, the next stage would not increase the GPM but would add 25 feet (7.5 m) more of head; each of the remaining eight stages would also add 25 feet (7.5 m) of head making the total 250 feet (75 m) of head. The capacity would remain at 500 GPM (32 *L*/sec). However, the brake horsepower for each stage is also additive (as is head). Therefore, if each stage requires 4 BHP (3 kilowatts), then the total for the ten stages would amount to 40 BHP (30 kilowatts).

---

[31] *Head. The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.*

[32] *Suction Lift. The NEGATIVE pressure [in feet (meters) of water or inches (centimeters) of mercury vacuum] on the suction side of a pump. The pressure can be measured from the centerline of the pump DOWN TO (lift) the elevation of the hydraulic grade line on the suction side of the pump.*

[33] *Pump Bowls. The submerged pumping unit in a well, including the shaft, impellers and housing.*

[34] *Brake Horsepower. (1) The horsepower required at the top or end of a pump shaft (input to a pump). (2) The energy provided by a motor or other power source.*

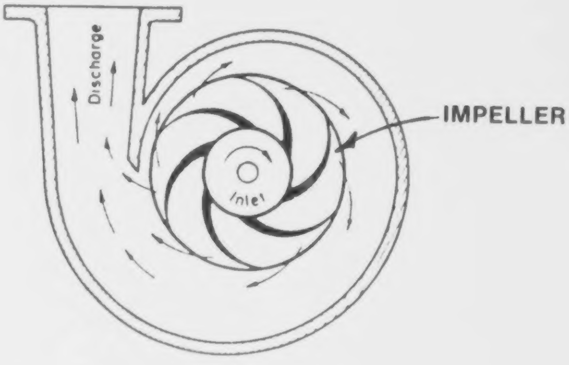
Well pumps for water utility operation are generally of the turbine design and often are referred to as variable-displacement deep-well centrifugal pumps or more simply, *DEEP-WELL TURBINE* pumps.

3.413 Deep-Well Turbine Pumps

There are two classifications of deep-well turbine pumps, depending upon the location of the prime mover (electric motor or engine).

1. *STANDARD DEEP-WELL TURBINE* pumps are driven through a rotating shaft (lineshaft) connected to an electric motor or engine mounted on top of the well (see Figure 3.17). This type of pump requires lubrication of the lineshaft connecting the motor and the pump. Manufacturers have incorporated both *OIL LUBRICATION* and *WATER LUBRICATION* into this design.

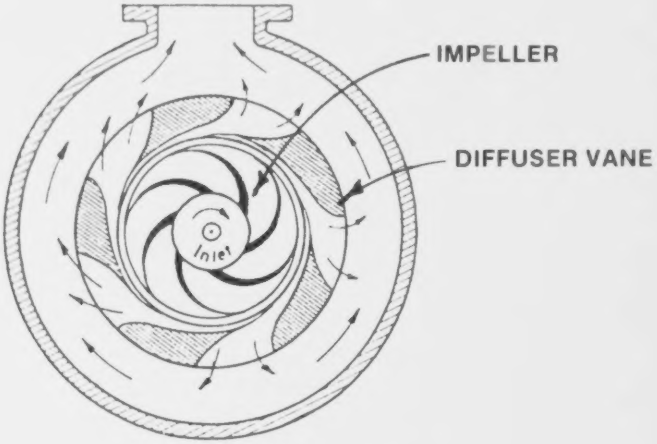
   a. In *WATER LUBRICATED* models, the lineshaft is supported in the center of the pump column pipe by means of stainless steel lineshaft sleeves equipped with neoprene bearings which are lubricated by the water as it flows upward in the column pipe (see Figure 3.18).



Volute-type, centrifugal pump has no diffuser vanes or guides.

Fig. 3.15 Volute-type pump

(Source: *GROUND WATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, Minn.)



In turbine-type pump, water leaving the impeller moves out through the curved passages between diffuser vanes.

Fig. 3.16 Turbine-type pump

(Source: *GROUND WATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, Minn.)

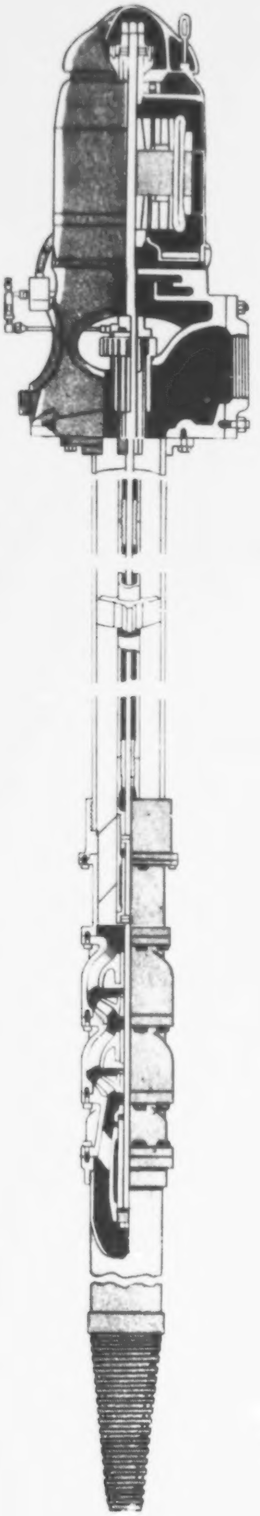


Fig. 3.17 Standard deep well turbine pump

(Permission of Jacuzzi Brothers, Inc.)

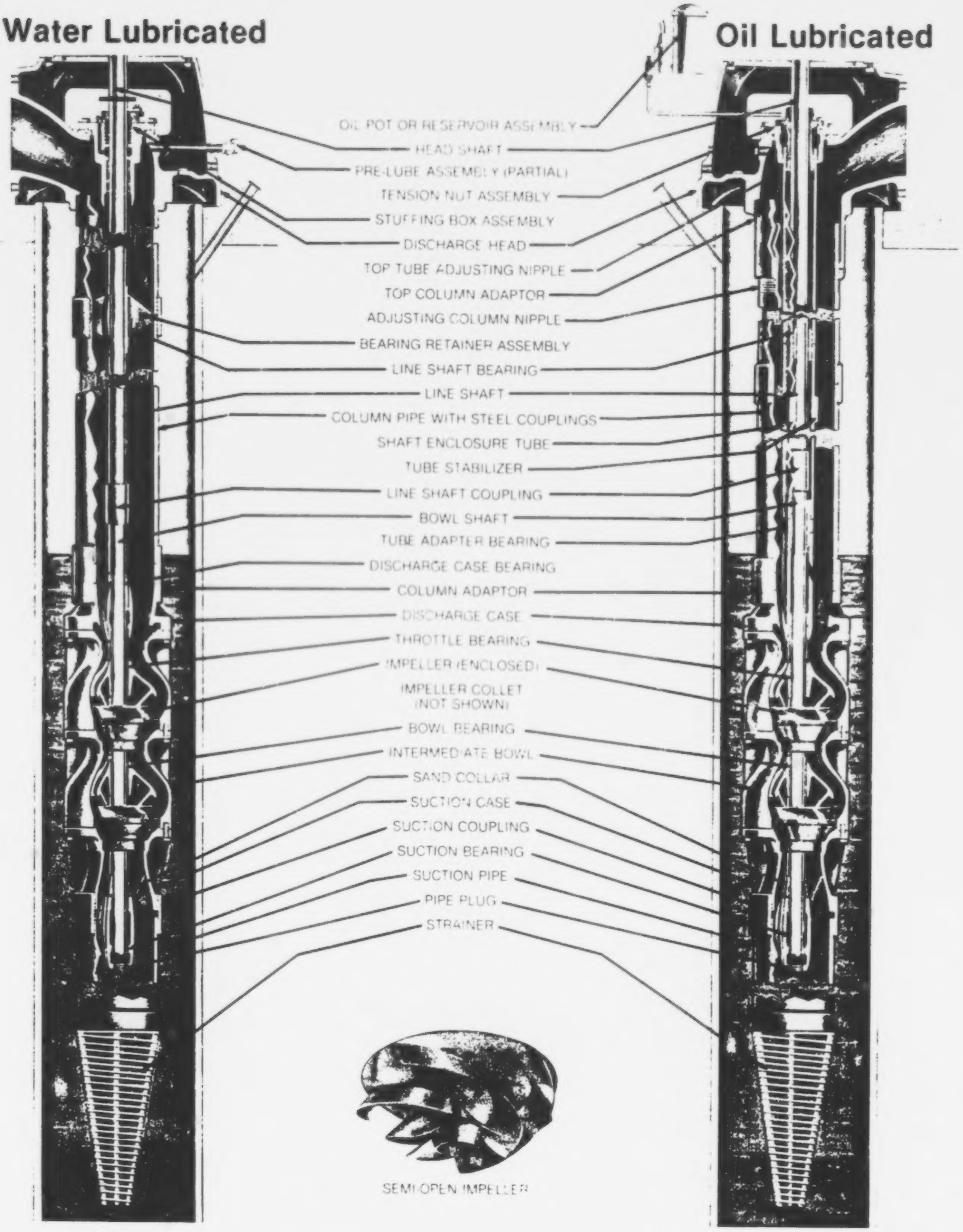

Water Lubricated
Oil Lubricated
OIL POT OR RESERVOIR ASSEMBLY
HEAD SHAFT
PRE-LUBE ASSEMBLY (PARTIAL)
TENSION NUT ASSEMBLY
STUFFING BOX ASSEMBLY
DISCHARGE HEAD
TOP TUBE ADJUSTING NIPPLE
TOP COLUMN ADAPTOR
ADJUSTING COLUMN NIPPLE
BEARING RETAINER ASSEMBLY
LINE SHAFT BEARING
LINE SHAFT
COLUMN PIPE WITH STEEL COUPLINGS
SHAFT ENCLOSURE TUBE
TUBE STABILIZER
LINE SHAFT COUPLING
BOWL SHAFT
TUBE ADAPTER BEARING
DISCHARGE CASE BEARING
COLUMN ADAPTOR
DISCHARGE CASE
THROTTLE BEARING
IMPELLER (ENCLOSED)
IMPELLER COLLET (NOT SHOWN)
BOWL BEARING
INTERMEDIATE BOWL
SAND COLLAR
SUCTION CASE
SUCTION COUPLING
SUCTION BEARING
SUCTION PIPE
PIPE PLUG
STRAINER
SEMI-OPEN IMPELLER

Fig. 3.18 Water lubricated pump

Fig. 3.19 Oil lubricated pump

(Permission of Peabody Floway Inc., Fresno, CA)

This type of pump is most commonly used for large capacity wells and is designed specifically for each well and for its intended function.

Pumping capacities generally range from 200 to 2,000 gallons per minute (12.6 to 126 liters per second).

b. *OIL LUBRICATED* models have a watertight oil tube surrounding the lineshaft and oil is fed from the surface (see Figure 3.19).

Although both oil and water lubricated pumps are used in water utility operation, oil lubricated pumps are most often used.

2. *SUBMERSIBLE DEEP-WELL TURBINE* pumps use a pumping bowl assembly similar to the standard deep-well turbine except that the motor is mounted directly beneath the bowl assembly. This eliminates the need for the lineshaft and oil tube (see Figure 3.20). Unit efficiency approaches that of a lineshaft turbine pump.

Submersible pumps are available in a wide range of capacities from 5 to 2,000 gallons per minute (0.3 to 126 liters/sec), and are used by individual well owners as well as by small and large water system operators.

Submersible pumps are ideally suited to small water system operation where source capacities range from 25 to 1,000 gallons per minute (1.5 to 63 liters/sec). Maintenance is minimal, the noise level is very low, and they are suited to installations that have limited building areas.

3.414 Other Pumps

There are numerous types of pumps that may be used in the water utility field such as those discussed in the following paragraphs.

1. *JET PUMPS*

These were used for years on individual wells prior to the development of submersible pumps. They are low in efficiency and are generally restricted to lifts of 100 feet (30 m) or less (see Figure 3.21).

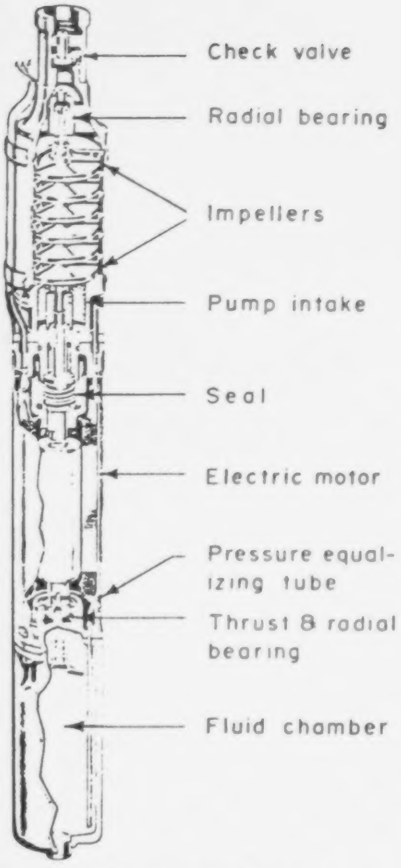
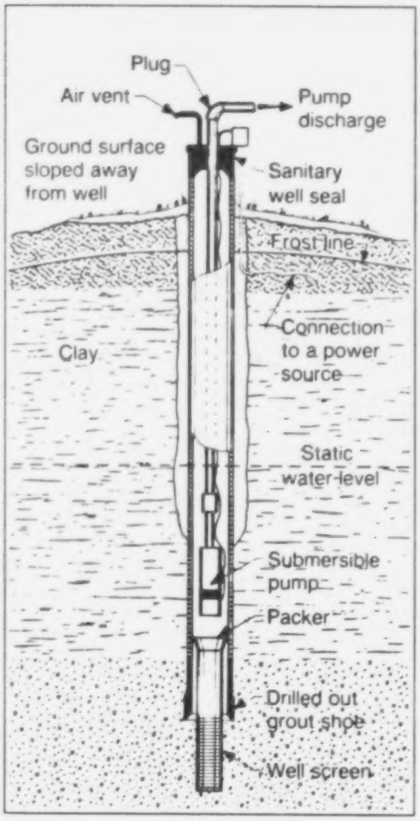

Check valve
Radial bearing
Impellers
Pump intake
Seal
Electric motor
Pressure equalizing tube
Thrust & radial bearing
Fluid chamber

Fig. 3.20 Submersible pump

(Source: *GROUND WATER AND WELLS*, Johnson Division, UOP, Inc., St. Paul, Minn.)


Plug
Air vent
Pump discharge
Ground surface sloped away from well
Sanitary well seal
Frost line
Connection to a power source
Clay
Static water level
Submersible pump
Packer
Drilled out grout shoe
Well screen

This well has been vented and sealed properly. The groundwater surface around the top of the casing has been graded to slope away in all directions. (*After U.S. Environmental Protection Agency, 1973*)

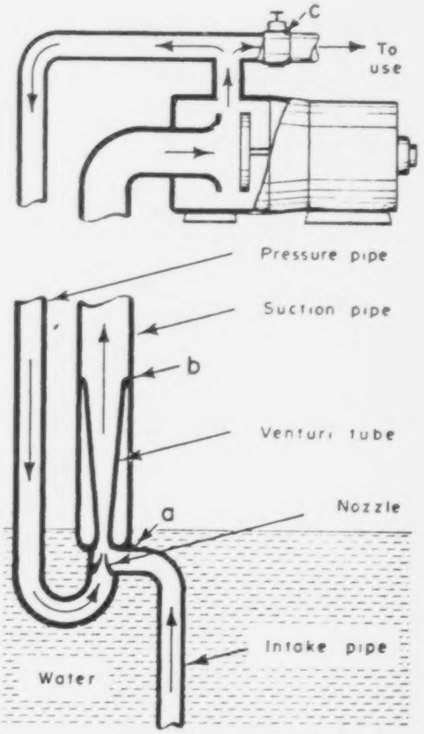
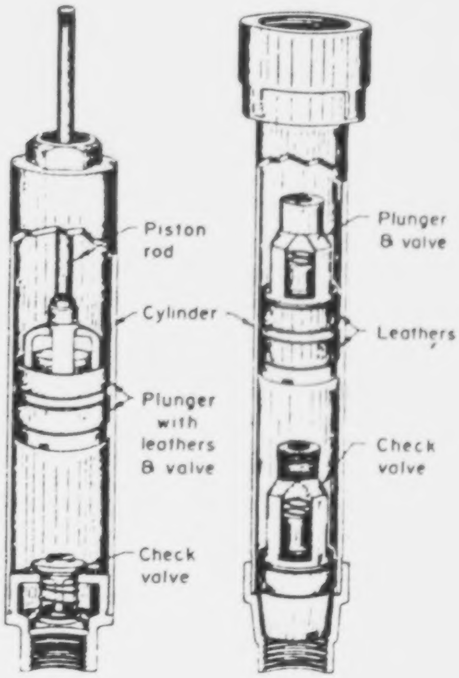

C
To use
Pressure pipe
Suction pipe
b
Venturi tube
Nozzle
a
Intake pipe
Water

Fig. 3.21 Typical jet pump

(Source: *GROUND WATER AND WELLS*, Johnson Division, UOP, Inc., St. Paul, Minn.)

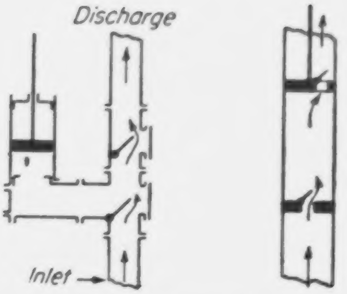
2. *PISTON PUMPS*

All piston pumps function by means of a piston movement which displaces water in a cylinder. The flow is controlled by valves. They are restricted to low capacity-high pressure applications and are being phased out in favor of turbine-type pumps (see Figure 3.22).



NOTE: Leathers are O rings or gaskets used to provide a seal between the piston and the side wall.

(Source: *GROUND WATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, Minn.)



SINGLE-ACTING PISTON PUMPS

Fig. 3.22 Typical piston pumps

(Reprinted from *WATER SUPPLY ENGINEERING* by Babbit, Dolan, and Cleasby, Sixth Edition, by permission. Copyright 1962, McGraw-Hill Book Company.)

3. *ROTARY PUMPS*

The rotary pump uses cogs or gears, rigid vanes and flexible vanes. When rotated, a gear-type pump squeezes the water from between the close-fitting gear teeth, moving the water from the inlet side to the outlet side of the pump. A typical rigid-vane rotary pump has a series of dividers or vanes fitted into a slotted rotor. When rotated, these vanes move radially to conform to the contour of the pump housing. The pump housing is eccentric with relation to the rotor, so that the water is pushed from the pump in a continuous flow ahead of the vanes. In flexible-vane rotary pumps, the vanes are elastic blades (usually rubber) which bend to provide the change in displacement volume which forces the water along its path. Rotary pumps are usually used for booster purposes and are generally used in conjunction with another pump (see Figure 3.23).

The above mentioned pumps have a very limited application and are discussed in this section for the purpose of familiarizing operators with pumps that could be found in water utility operations.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 116.

3.4A What are the two basic groups of well pumps and the differences between them?

3.4B List as many advantages of a centrifugal pump as you can recall.

3.4C Why is the installation of jet pumps not too common today?

3.42 Column Pipe

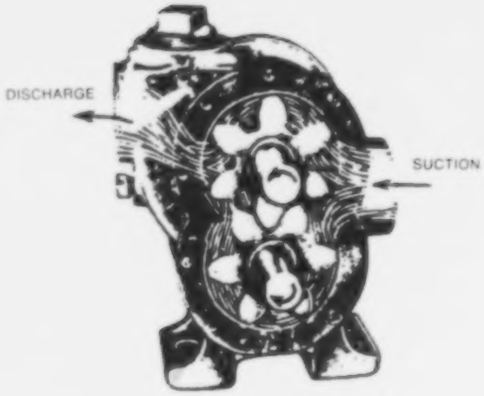
Operators should be aware of the functions of the pump column pipe in a deep-well turbine pumping installation. The column pipe is an integral part of the pump assembly and serves three basic purposes: (1) the column pipe connects to the bottom of the surface discharge head, extends down into the well and connects to the top of the well pump (bowl unit) thereby supporting the pump in the well, (2) the column pipe delivers water under pressure from the well pump to the surface, and (3) keeps the lineshaft and shaft enclosing (oil) tube assembly in straight alignment. Column pipe assemblies for both water and oil lubricated pumps are shown in Figures 3.24 and 3.25.

3.43 Right-Angle Gear Drives (Figures 3.26 and 3.27)

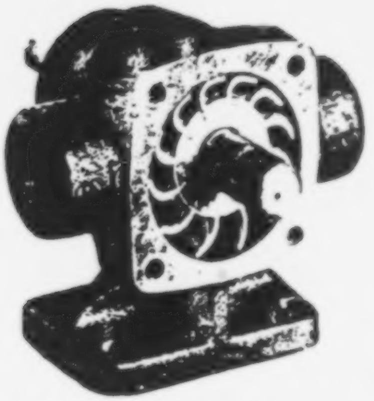
Right-angle gear drives for water utility operations have two distinct applications and provide an economical, efficient, and positive power transmission from a horizontal prime mover (electric motor or engine) to a vertical shaft.

In one application, the right-angle gear drive replaces the electric motor on top of the well and is used on either a full-time or part-time basis.

In a second application, the right-angle gear drive is used with the electric motor. The gear drive is mounted on top of the well discharge head and the electric motor is connected to the right-angle gear drive. An extra long headshaft (an extension of the lineshaft) connects both prime movers to the bowl unit in the well. In most applications, the electric

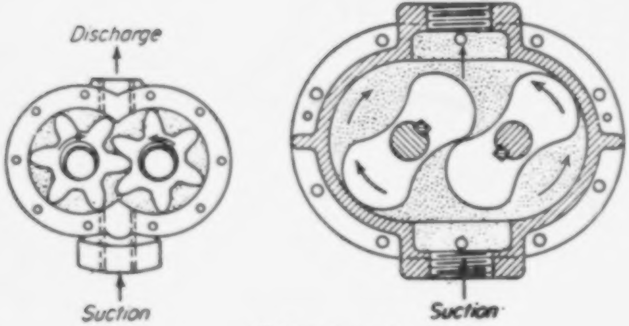

DISCHARGE
SUCTION

Rotary gear pump



Typical design of flexible vane rotary pump

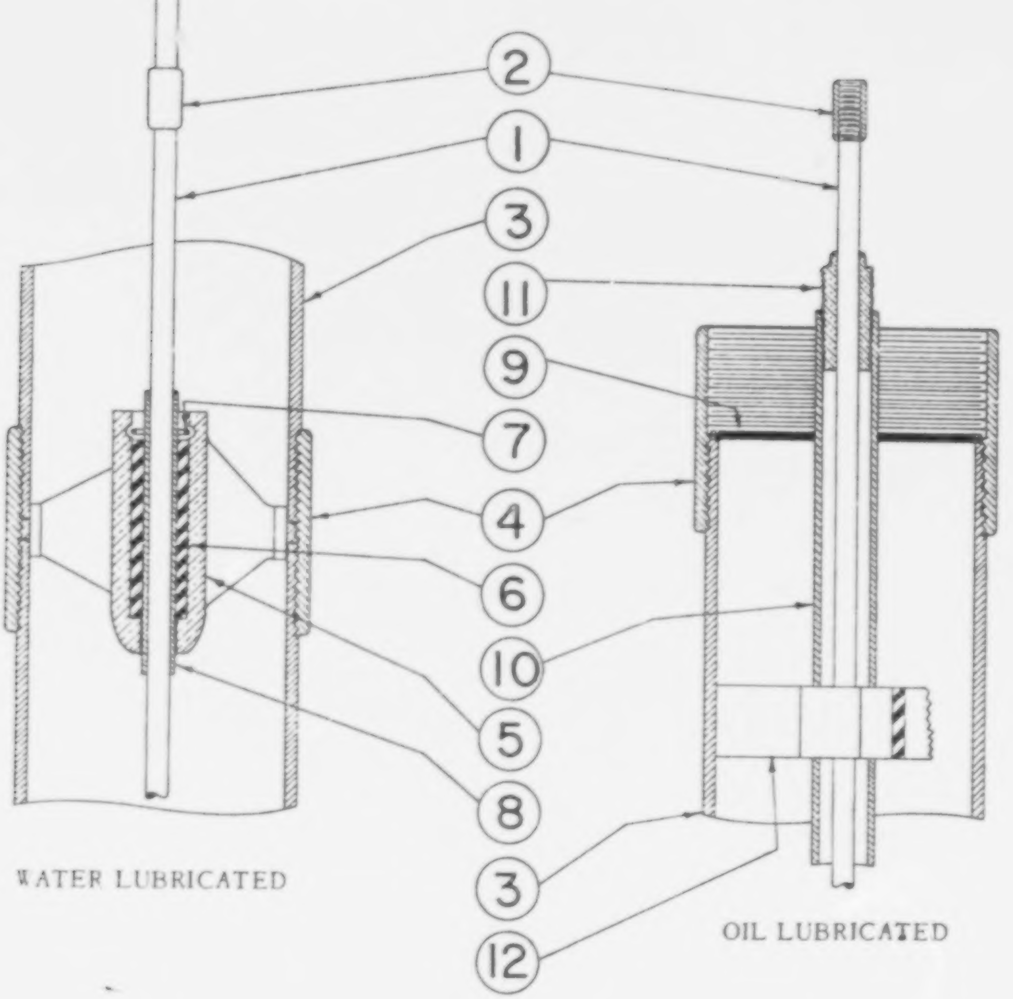
(Source: *GROUND WATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, Minn.)


Discharge
Suction
Discharge
Suction

Rotary pumps

(Reprinted from *WATER SUPPLY ENGINEERING* by Babbit, Dolan, and Cleasby, Sixth Edition, by permission. Copyright 1962, McGraw-Hill Book Company.)

Fig. 3.23 Rotary pumps


2
1
3
11
9
7
4
6
10
5
8
3
12
WATER LUBRICATED
OIL LUBRICATED

1 LINE SHAFT
2 SHAFT COUPLING
3 COLUMN PIPE
4 COLUMN PIPE COUPLING
5 BEARING CAGE
6 RUBBER SHAFT BEARING

7 SNAP RING
8 SHAFT SLEEVE
9 COLUMN PIPE SPACER RING (OPTIONAL)
10 OIL TUBE
11 LINE SHAFT BEARING
12 TUBE STABILIZER

Fig. 3.24 Column pipe assembly for water lubricated pumps

Fig. 3.25 Column pipe assembly for oil lubricated pumps

(Permission of Peabody Floway, Inc., Fresno, CA)

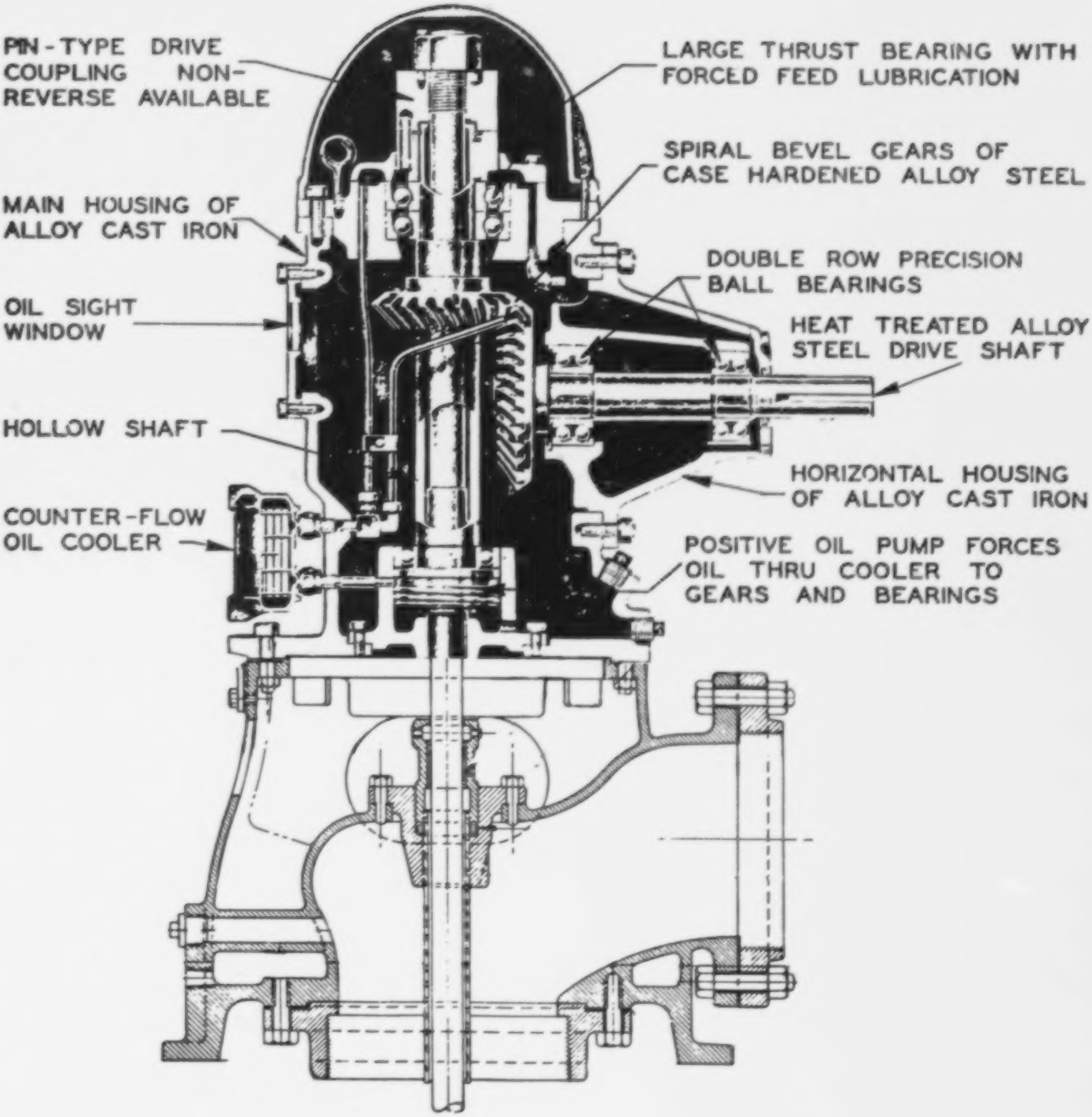

PIN-TYPE DRIVE COUPLING NON-REVERSE AVAILABLE
LARGE THRUST BEARING WITH FORCED FEED LUBRICATION
SPIRAL BEVEL GEARS OF CASE HARDENED ALLOY STEEL
MAIN HOUSING OF ALLOY CAST IRON
DOUBLE ROW PRECISION BALL BEARINGS
OIL SIGHT WINDOW
HEAT TREATED ALLOY STEEL DRIVE SHAFT
HOLLOW SHAFT
HORIZONTAL HOUSING OF ALLOY CAST IRON
COUNTER-FLOW OIL COOLER
POSITIVE OIL PUMP FORCES OIL THRU COOLER TO GEARS AND BEARINGS

Fig. 3.26 Right-angle pump drive

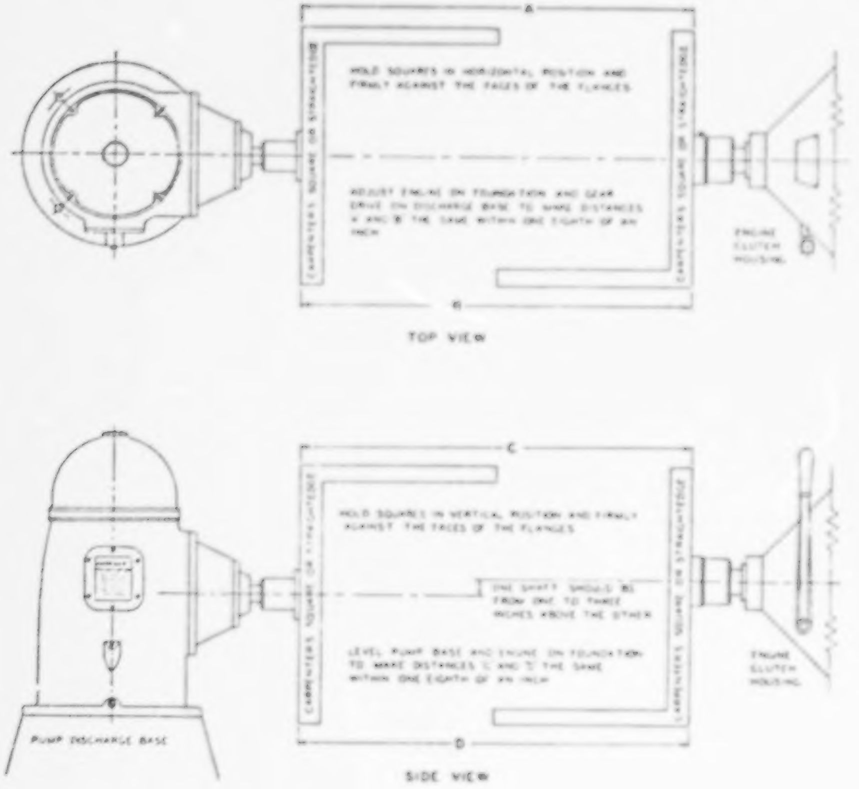

A
HOLD SQUARES IN HORIZONTAL POSITION AND FIRMLY AGAINST THE FACES OF THE FLANGES
ADJUST ENGINE ON FOUNDATION AND GEAR DRIVE ON DISCHARGE BASE TO MAKE DISTANCES A AND B THE SAME WITHIN ONE EIGHTH OF AN INCH
CARPENTERS SQUARE OR STRAIGHTEDGE
ENGINE CLUTCH HOUSING
B
TOP VIEW
C
HOLD SQUARES IN VERTICAL POSITION AND FIRMLY AGAINST THE FACES OF THE FLANGES
ONE SHAFT SHOULD BE FROM ONE TO THREE INCHES ABOVE THE OTHER
LEVEL PUMP BASE AND ENGINE ON FOUNDATION TO MAKE DISTANCES C AND D THE SAME WITHIN ONE EIGHTH OF AN INCH
CARPENTERS SQUARE OR STRAIGHTEDGE
ENGINE CLUTCH HOUSING
PUMP DISCHARGE BASE
D
SIDE VIEW

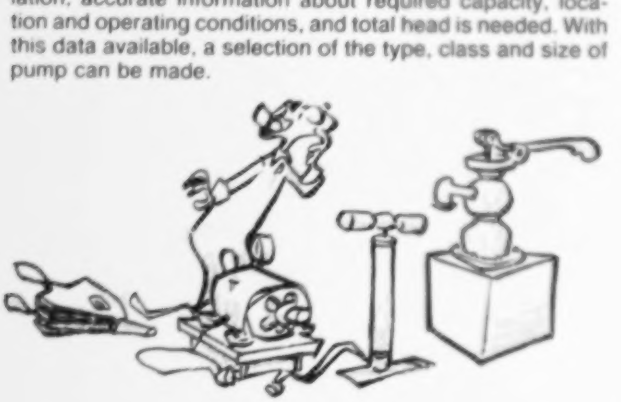
Fig. 3.27 Alignment of right angle pump drive
(Source: Amarillo Right Angle Pump Drive, Amarillo, Texas)

motor is the lead prime mover and the right-angle gear drive unit is used for standby or emergency purposes only. The unit is usually set up for automatic operation.

In either application, the prime mover could be in the form of a gasoline, natural gas, diesel, or propane-powered engine connected to the gear head by means of a flexible drive shaft.

3.44 Selecting a Pump

Before a pump can be intelligently selected for any installation, accurate information about required capacity, location and operating conditions, and total head is needed. With this data available, a selection of the type, class and size of pump can be made.



After the best type of pump has been determined on the basis of available data, an individual pump must be selected which will best fit each situation. This selection is particularly important if a well is the source of water supply and must take into account differences in pumping head caused by seasonal variations of static water level, temporary lowering of the pumping water level as a result of long periods of continuous pumping, and interference from other wells in the area.

3.45 Service Guidelines

DEEP-WELL TURBINE OIL-LUBRICATED pumps are usually equipped with an automatic electric oiler system that is activated by means of an electronic solenoid valve when the well pump starts. An adjusting needle and sight glass are part of this assembly. The needle valve is adjusted to feed approximately five drops per minute plus one drop of oil per minute for each 20 feet (6 m) of column during the first week of operation. The drip rate may thereafter be reduced to one drop per minute for each 40 feet (12 m) of column. Under no circumstances should the drip rate be less than five drops per minute, regardless of the length of column.

A good grade of turbine oil (mineral base) SAE 10 is used as the lubricant. Automotive or diesel engine lubricating oils cannot be used as a lineshaft lubricant. The oils listed in Table 3.1 are recommended for lubricating the lineshaft bearings. This list does not include all acceptable oils.

TABLE 3.1 OILS RECOMMENDED FOR LUBRICATING THE LINESHAFT BEARINGS[a]

OIL	*SOURCE*
Turbine Oil, Light	Atlantic Refining
Teresso, #43	ESSO Standard
Gulfcrest, #44	Gulf
Turbo, #27	Shell
DTE, #797	Socony Mobil
Chevron OC Turbine, #9	Standard Oil of Calif.
Nonpareil, Medium L5803	Standard Oil of Ind.
Sunvise, #916	Sun Oil
Regal, R & O	The Texas Company
Pacemaker, #1	Cities Service

[a] *JOHNSTON VERTICAL TURBINE PUMPS, INSTALLATION, OPERATION AND MAINTENANCE MANUAL*, Glendora, Ca.

DEEP-WELL TURBINE WATER LUBRICATED pumps are self lubricating and normally require little or no lineshaft maintenance. In a few cases where the static water level is over 100 feet (30 m) and the pump is operated on an intermittent basis, a special small-diameter pressurized water line may be used to keep the bearings above the water level lubricated.

3.46 Motors

Vertical, hollow-shaft motors for deep-well turbine pumps (motor on top of well) require some degree of routine maintenance. The motor bearings at the top and bottom of the motor are enclosed within a weatherproof oil bath container. The oil in this container should be changed annually. Most motors are equipped with a lubrication instruction plate attached to the motor that specifies the proper type and viscosity of oil required for various operating temperatures.

On small motors, the bearings are generally grease lubricated and require weekly attention during the heavy pumping season. The motor manufacturer's instruction manual should specify the type of grease recommended for various applications.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 117.

3.4D List the three basic purposes of the pump column pipe in a deep-well turbine pumping installation.

3.4E What are the prime movers used with right-angle gear drives?

3.4F How are deep-well turbine oil-lubricated pumps lubricated?

3.5 DISINFECTION OF WELLS AND PUMPS

(Also see Chapter 9, "Disinfection")

3.50 New Wells — During Construction

During the drilling of new wells, contamination could be introduced into the well from the drilling tools and mud, make-up water, topsoil falling in or sticking to tools, and from the gravel itself.

The procedure described below is generally satisfactory for disinfecting a well; however, other methods may be used provided it can be demonstrated that they will produce comparable results. Disinfection should take place following development, testing for yield, and before the test pump is removed from the well. This will assure that the well is purged of drilling mud, dirt, and other debris that reduces the effectiveness of the disinfecting solution.

1. Add to the well a chlorine solution strong enough to produce a chlorine concentration of 50 mg/*L* *IN* the well casing. Table 3.2 lists quantities of various chlorine compounds required to dose 100 feet (30 meters) of water-filled casing at 50 mg/*L* for diameters ranging from 6 to 24 inches (150 to 600 mm). Since organic matter such as oil may need an initial concentration of 1000 mg/*L* before being injected into the well. This is 20 times the values in Table 3.2.

TABLE 3.2 CHLORINE COMPOUNDS REQUIRED TO DOSE 100[a,b] FEET OF WATER-FILLED CASING AT 50 MILLIGRAMS PER LITER

	Chlorine Compounds		
Diameter of Casing (inches)	: Calcium Hypochlorite (65%), Sold as : HTH or Perchloron (Dry Weight)[c,d]	Chloride of Lime (25%) : (Dry Weight)[c,d]	Sodium Hypochlorite (5.25%), Sold as Purex or Clorox (Liquid Measure)[e]
6	2 ounces	4 ounces	20 ounces
8	3 ounces	7 ounces	2⅛ pints
10	4 ounces	11 ounces	3½ pints
12	6 ounces	1 pound	5 pints
16	11 ounces	1¾ pounds	1 gallon
20	1 pound	3 pounds	1⅔ gallons
24	1½ pounds	4 pounds	2⅔ gallons

[a] *WATER WELL STANDARDS*, Bulletin 74, California Department of Water Resources, Sacramento, Ca.

[b] Some authorities recommend a minimum concentration of 100 mg/*L*. To obtain this concentration, double the amounts shown.

[c] Where a dry chemical is used, it should be mixed with water to form a chlorine solution prior to placing it into the well. HTH stands for High Test Hypochlorite which is calcium hypochlorite or $Ca(OCl)_2$.

[d] 16 ounces = 1 pound (Dry Weight)

[e] 16 fluid ounces = 1 pint; 2 pints = 1 quart; 4 quarts = 1 gallon

2. Turn the pump on and off several times so as to thoroughly mix the disinfectant with the water in the well. Pump until the water discharged has the odor of chlorine. Repeat this procedure several times at one-hour intervals.
3. Allow the well to stand without pumping for 24 hours.
4. The water should then be pumped to waste until the odor of chlorine is no longer detectable. Use a chlorine test kit to determine the absence of a chlorine residual.
5. Collect a bacteriological sample in a sterile container and submit it to a laboratory for examination.
6. If the laboratory analysis shows the water is not free of bacterial contamination, repeat the disinfection procedure and retest the water. If repeated attempts to disinfect the well are unsuccessful, a detailed investigation to determine the cause of the contamination should be undertaken.

3.51 New Wells — After Construction

Prior to placing a new well pumping installation in service, the well disinfection procedure previously described should be repeated. This will protect against contamination caused during the construction of the pump base and related appurtenances, and the installation of the permanent pumping unit.

3.52 Existing Wells — After Well or Pump Repairs

Disinfection of existing wells following repairs to the well or replacement of pumping equipment may require special disinfection methods. During the repair work deposits of slime, bacterial growth, and other debris are dislodged from the inside surfaces of the well casing and from the outside surfaces of the well pump column pipe. These deposits generally settle to the bottom of the well, but some are also smeared on the inside surfaces of the well casing, particularly above the water line. Those deposits above the water line are difficult to disinfect by typical well disinfection procedures. The following special procedures are recommended.

1. Swab inside of well casing with a strong non-foaming detergent such as trisodium phosphate or Calgon.
2. Calculate amount of chlorine based on diameter of well and water depth. The chlorine dosage rate should produce a free chlorine concentration of at least *100* mg/*L* in the water-filled casing.
3. Add chlorine solution to the well, preferably through a hose raised and lowered to reach all areas of the well, including the well casing above the water line.
4. Clean and disinfect pump, pump column pipe, cable, and other equipment before the units are lowered into the well.
5. Follow procedures 2 through 6 for new well disinfection (Section 3.50).

3.53 Contaminated Wells

If the well and pumping unit must be disinfected because of contamination or bacterial problems and *THE WELL PUMP IS LEFT IN PLACE*, then follow these *SPECIAL METHODS*:

1. To the well* add a chlorine solution, strong enough that it produces a chlorine concentration of *200 mg/L IN THE WELL CASING*. (*See Sections A and B below for procedures on how to add the chlorine solution to the well.)
2. Turn the pump on and off several times to thoroughly mix the disinfectant with the water in the well. Pump until the water discharged has the odor of chlorine. Repeat this procedure several times at one-hour intervals.
3. Allow the well to stand without pumping for 24 hours.
4. Pump the water to waste until the odor of chlorine is no longer detectable. A chlorine test kit should be used to determine the absence of a chlorine residual.
5. Take a bacteriological sample and submit it to a laboratory for examination.
6. If the laboratory analysis shows the water is not free of bacterial contamination, repeat the disinfection procedure and retest the water. If repeated attempts to disinfect the well are unsuccessful, a detailed investigation to determine the cause or source of the contamination should be undertaken.

*A *SUBMERSIBLE PUMPS AND DEEP WELL TURBINE PUMPS — WATER LUBRICATED*

The chlorine solution should be introduced into the well through either the air release valve piping assembly (remove air release valve) or the well casing vent, and water added to flush the chlorine solution back into the well. If the well is equipped with a foot valve, then the chlorine solution must be introduced into the well via the well casing vent.

*B *DEEP WELL TURBINE PUMPS — OIL LUBRICATED*

Introduce the chlorine solution into the well through the air release valve piping assembly as described in (A) above. Chlorine solution or chlorine powder should not be added to the well by means of the well casing vent. Nearly all oil lubricated pumps have a certain amount of oil floating on the surface of the water within the well casing, ranging from a thin film to twenty feet (6 m) or more. Chlorine added through the well casing vent strikes the oil floating on the surface of the well and carries oil and debris down into the well and makes *CLEANUP DIFFICULT*. If it is absolutely necessary to apply chlorine by means of the well casing vent, then a chlorine solution should be introduced into the well through a hose raised and lowered to reach all areas of the well below the level of the oil. If this method cannot be used, then resort to chlorine tablets. If tablets are used, allow sufficient dissolving time and follow Section 3.50, Step 2, procedure for new wells.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 117.

3.5A How could contamination be introduced during the drilling of a new well?

3.5B When should a well be disinfected?

3.5C When disinfecting a new well, what is the desired chlorine concentration in the well casing?

3.5D Why does the disinfection of existing wells after well or pump repairs require special disinfection methods?

3.5E What would you do if repeated attempts to disinfect a well are unsuccessful?

3.54 Chlorine Requirement Calculation

The amount of a chlorine compound required to disinfect a well may be determined by two different methods. The first method is the easier and uses values from Table 3.2. The second method calculates the amount of chlorine required based on the volume of water in the casing being disinfected, the desired chlorine dose and the amount of chlorine available in the disinfecting chlorine compound. Both methods will give the same results with the second method being slightly more accurate.

FORMULAS

Method 1

$$\text{Chlorine Required} = \frac{(\text{Table 3.2 Value})\ (\text{Casing Length, ft})}{100\ \text{ft}}$$

To find the value in Table 3.2, you need to know:

1. Diameter of casing in inches, and
2. Type of chlorine compound.

The length of water-filled casing in feet is used to calculate the chlorine required. Also, Table 3.2 assumes the desired chlorine dose is 50 mg/*L*. If the dose is not 50 mg/*L*, use the following formula:

$$\begin{array}{l}\text{Chlorine Required}\\ \text{(If dose not}\\ \text{50 mg/}L\text{)}\end{array} = \frac{(\text{Chlorine Required})\ (\text{Desired Dose, mg/}L)}{50\ \text{mg/}L}$$

Calculate the "Chlorine Required" using Table 3.2 and then adjust this answer by multiplying by the "Desired Dose, mg/*L*" and dividing by "50 mg/*L*."

Method 2

$$\begin{array}{l}\text{Casing}\\ \text{Volume,}\\ \text{gal}\end{array} = \frac{(0.785)\ (\text{Casing Diameter, in})^2 (\text{Casing Length, ft})\ (7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$\begin{array}{l}\text{Chlorine}\\ \text{Required,}\\ \text{gal}\end{array} = \frac{(\text{Casing Volume, gal})\ (\text{Desired Dose, mg/}L)}{\text{Chlorine Compound Solution, mg/}L}$$

To determine the chlorine required using Method 2 requires two steps. The first step calculates the casing volume in gallons. The second step calculates the chlorine required by multiplying the casing volume in gallons times the desired chlorine dose in mg/*L* and dividing by the chlorine concentration in the chlorine compound solution in mg/*L*. A one percent (1%) chlorine solution is the same as a 10,000 mg/*L* chlorine solution.

EXAMPLE 1

How much sodium hypochlorite is required to dose a well at 50 mg/*L*? The casing diameter is 6 inches and the length of water-filled casing is 150 feet. Sodium hypochlorite is 5.25 percent or 52,500 mg/*L* chlorine.

Known		Unknown
Casing Diameter, in	= 6 in	Chlorine Required, gal
Casing Length, ft	= 150 ft	
Chlorine Compound, mg/*L* (Sodium Hypochlorite)	= 52,500 mg/*L*	

Method 1

1. Find the chlorine required from Table 3.2 for a 6-inch diameter well casing when using sodium hypochlorite.

   Table 3.2 Value = 20 ounces

2. Calculate the ounces of chlorine required.

$$\begin{array}{l}\text{Chlorine}\\ \text{Required,}\\ \text{ounces}\end{array} = \frac{(\text{Table 3.2 Value})(\text{Casing Length, ft})}{100\ \text{ft}}$$

$$= \frac{(20\ \text{ounces})(150\ \text{ft})}{100\ \text{ft}}$$

$$= 30\ \text{ounces}$$

3. Convert the chlorine required from ounces to gallons of sodium hypochlorite.

$$\begin{array}{l}\text{Chlorine}\\ \text{Required,}\\ \text{gal}\end{array} = \frac{(\text{Chlorine Required, ounces})}{(16\ \text{ounces/pint})(8\ \text{pints/gallon})}$$

$$= \frac{30\ \text{ounces}}{(16\ \text{ounces/pint})(8\ \text{pints/gallon})}$$

$$= 0.23\ \text{gallons}$$

Method 2

1. Calculate the water-filled casing volume in gallons.

$$\begin{array}{l}\text{Casing}\\ \text{Volume,}\\ \text{gal}\end{array} = \frac{(0.785)(\text{Casing Diameter, in})^2(\text{Casing Length, ft})(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$= \frac{(0.785)(6\ \text{in})^2(150\ \text{ft})(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$= 220\ \text{gal}$$

2. Calculate the required gallons of sodium hypochlorite.

$$\begin{array}{l}\text{Chlorine}\\ \text{Required,}\\ \text{gal}\end{array} = \frac{(\text{Casing Volume, gal})(\text{Desired Dose, mg/}L)}{\text{Chlorine Compound Solution, mg/}L}$$

$$= \frac{(220\ \text{gal})(50\ \text{mg/}L)}{52{,}500\ \text{mg/}L)}$$

$$= 0.21\ \text{gallons}$$

NOTE: We obtained essentially the same answer by either method. Table values will tend to be slightly higher and on the safe side.

QUESTION

Write your answers in a notebook and then compare your answers with those on page 117.

3.5F How much sodium hypochlorite is required to dose a well at 50 mg/*L*? The casing diameter is 12 inches and the length of water-filled casing is 200 feet.

End of Lesson 3 of 4 Lessons
on
WELLS

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. WELLS

(Lesson 3 of 4 Lessons)

Write the answers to these questions in your notebook before continuing with Lesson 4. The problem numbering continues from Lesson 2.

11. What is the difference between a shallow well pump and a deep well pump?
12. How does a centrifugal pump work?
13. Under what conditions are submersible deep-well turbine pumps commonly used?
14. Under what circumstances should a well be disinfected?
15. What chlorine compounds are commonly used to disinfect wells?

WELL! WELL! WELL!

CHAPTER 3. WELLS

(Lesson 4 of 4 Lessons)

3.6 OPERATOR RESPONSIBILITY AND RECORDKEEPING

3.60 Health and Safety

Properly designed and constructed well pumping stations should produce water in sufficient quantity and quality to meet the needs of the entire community. If the pumping stations fail to do so, the fault can often be traced to poor operation or neglect. The health and safety of the water users depends on good operation.

3.61 Operator Responsibility

All operators have the responsibility to exercise due care and diligence to protect the water sources under their surveillance; to effectively operate and maintain the water production facilities; and to take corrective action as necessary to assure that safe and potable water in adequate quantities and pressure is continuously supplied to the water users in the community.

3.62 Knowledge of the Water Production Facilities

All operators should have a working knowledge of all of the component parts of a well pumping station and completely understand the role each individual part performs in the overall operation of the facility.

3.63 Routine Facility Servicing

The frequency of routine service calls to a well pumping facility usually depends on the nature and importance of the pumping facility and the availability of personnel.

In small utility operations the manager may also perform the duties of operator, meter reader, and maintenance personnel.

In large utility operations a full-time staff of qualified operators is usually available including personnel trained in removing and replacing pumping equipment and electrical components.

Regardless of the size of the water utility, the pumping stations must be checked often enough to assure that the facility components are receiving proper servicing, that routine maintenance functions are performed, that the plant is operational and capable of producing safe water, and the security of the plant is intact.

The frequency of service calls for small utility operations may be two or three per week, while a large utility may check their facilities daily including weekends and holidays.

3.64 What To Look For

LOOK, LISTEN, and *FEEL* is not intended as a pun. When the operator enters the pumping facility a complete visual inspection of the facility should be made, including listening for any unusual noises and feeling for vibrations on pieces of equipment such as motors and pumps.

3.65 Forms

Some type of inspection form should be available for the operator to record pertinent data relative to the operation of the pumping facility. Various types of forms have been developed based upon the individual preferences of the utility and the characteristics of the facility. Figure 3.28 is a typical example of a form that could be used by the average water utility.

A monthly operational record should be maintained for each well pumping facility. This record should be filled out each time the operator visits the well pumping facility either for routine service or for other purposes.

The items of information to record will vary depending upon the type of installation, but generally speaking the following items are necessary:

1. Date and time of service visit.
2. Water production meter reading.
3. Electric power meter reading. (Optional)
4. Amount of lineshaft oil added.
5. Oil level if motor is equipped with motor bearing oil reservoir.
6. Greasing frequency.
7. Air level in pressure tank.
8. Water level in storage tank if well pumps directly to tank.
9. Status of chlorination equipment, including feed rate and amount of chlorine used. (Scales or graduated solution tank required.)
10. Standing water level in well. (Recommend monthly, but could be performed quarterly.)
11. General operation and appearance of facility. Note any unusual conditions or observations such as noise, vibration, and signs of vandalism.

3.66 Records

In previous sections we have discussed the importance of maintaining good records. We cannot over-stress that recordkeeping is an extremely important part of any water purveyor's operation. Often, recordkeeping for the small water system operator is minimal at best. The operator must realize that there is *NO SUBSTITUTE FOR GOOD RECORDS.*

Due to the variety and size of the various types of water utilities, it is difficult to set forth a specific guideline as to what type of records should be maintained.

As a minimum, recordkeeping should cover the following areas of operation:

1. *NEW CONSTRUCTION RECORDS*

   New water facilities added to the system (wells, pumps, boosters, storage tanks, water mains, chlorination equipment) should be adequately recorded on an "as built" drawing showing type and location of facilities installed.

   For well pumping stations, this should also include copies of the well drillers' report, well log, pump suppliers' equipment sheet with performance curves, construction details of the pump base and related appurtenances, motor specifications, pump controls, wiring diagrams, parts list and operating instructions.

2. *EQUIPMENT RECORDS*

   Individual equipment items should have the manufacturers' specifications and literature available for review along with any warranty documents.

3. *REPAIRS AND MODIFICATIONS*

   Records of repairs and modifications to well pumping facilities should be accurately maintained with a drawing showing what work was done.

Many states require that well drillers file a "Water Well Drillers Report" upon completion of the well. The well owner receives a copy of this report. If the well driller is accurate in filling out this report, then it could be a very important document for the well owner's file. Figure 3.29 is a copy of a report required in California by the State Department of Water Resources.

Figures 3.30 and 3.31 are examples of forms used for recording pump information.

Figure 3.32 is a self-inspection form that could be used by the operator as a starting point towards maintaining adequate records.

The length of time that records must be kept from a legal standpoint is generaly considered to be seven years. However, records pertaining to wells, equipment, water production, and other pertinent data should be kept longer than seven years.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 117.

3.6A What might cause a properly designed and constructed well pumping station to fail to produce water in sufficient quantity and quality to meet the needs of the entire community?

3.6B What should an operator do when entering a pumping facility for an inspection?

3.6C Recordkeeping should cover what areas of operation?

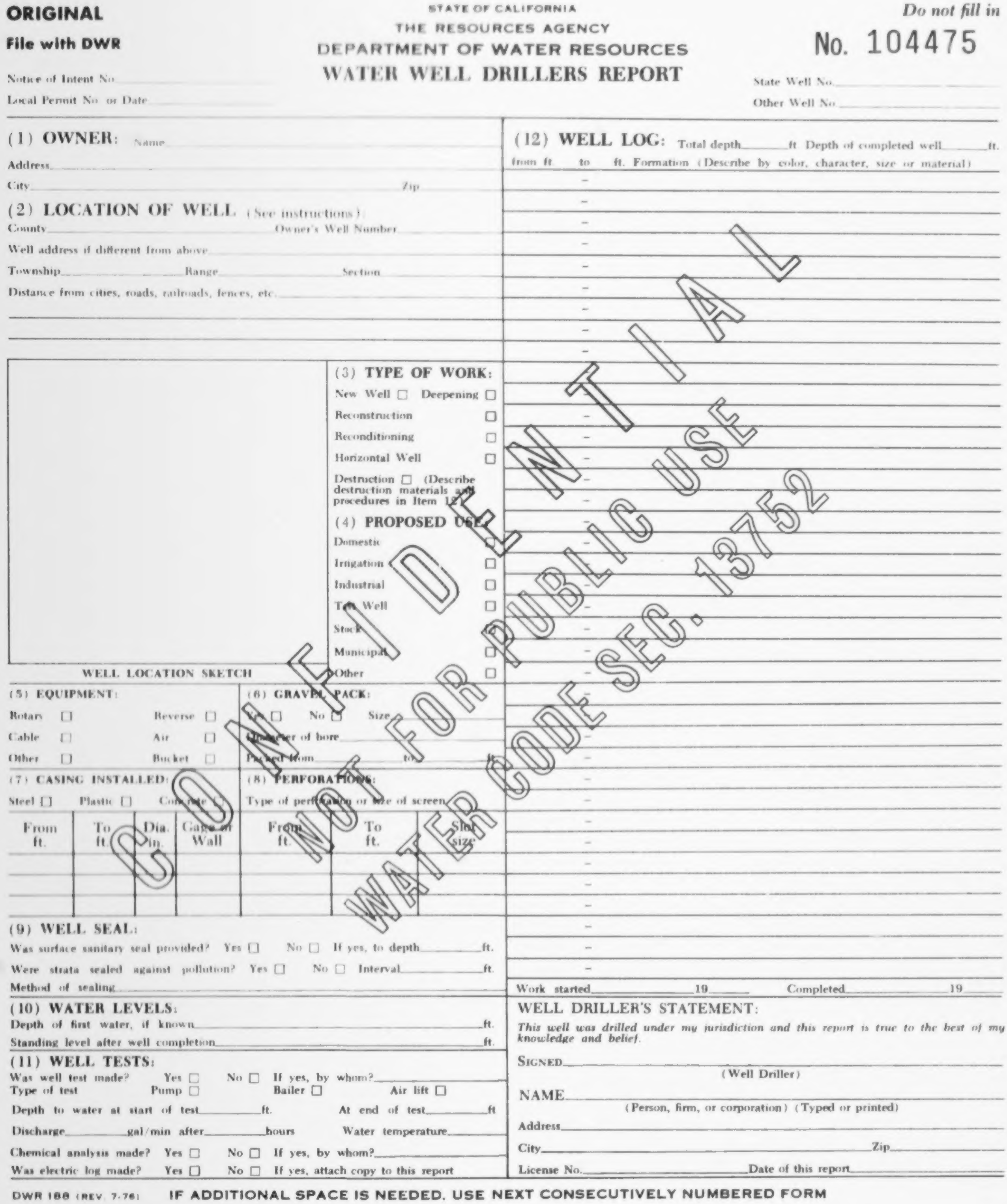
3.7 SAND IN WELL WATER SYSTEMS

3.70 Sources of Sand

Nearly all wells produce a certain amount of sand. Every reasonable effort should be made to prevent sand particles from entering the distribution system.

DATE	TIME	METER READING IN GALLONS	WATER PRODUCTION IN GALLONS	DISCHARGE PRESSURE	AIR LEVEL IN TANK	LUBE OIL ADDED	STANDING WATER LEVEL	OPERATOR	REMARKS
31									
30									
29									
28									
27									
26									
25									
24									
23									
22									
21									
20									
19									
18									
17									
16									
15									
14									
13									
12									
11									
10									
9									
8									
7									
6									
5									
4									
3									
2									
1									
LAST DAY OF PREVIOUS MONTH									
TOTAL									

Fig. 3.28 Pumping facility inspection form



ORIGINAL
File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
WATER WELL DRILLERS REPORT

Do not fill in
No. 104475

Notice of Intent No.
Local Permit No. or Date
State Well No.
Other Well No.

(1) OWNER: Name
Address
City Zip

(2) LOCATION OF WELL (See instructions):
County Owner's Well Number
Well address if different from above
Township Range Section
Distance from cities, roads, railroads, fences, etc.

WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☐ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☐
Stock ☐
Municipal ☐
Other ☐

(5) EQUIPMENT:
Rotary ☐ Reverse ☐
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☐ No ☐ Size
Diameter of bore
Packed from to ft.

(7) CASING INSTALLED:
Steel ☐ Plastic ☐ Concrete ☐

(8) PERFORATIONS:
Type of perforation or size of screen

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size

(9) WELL SEAL:
Was surface sanitary seal provided? Yes ☐ No ☐ If yes, to depth ft.
Were strata sealed against pollution? Yes ☐ No ☐ Interval ft.
Method of sealing

(10) WATER LEVELS:
Depth of first water, if known ft.
Standing level after well completion ft.

(11) WELL TESTS:
Was well test made? Yes ☐ No ☐ If yes, by whom?
Type of test Pump ☐ Bailer ☐ Air lift ☐
Depth to water at start of test ft. At end of test ft
Discharge gal/min after hours Water temperature
Chemical analysis made? Yes ☐ No ☐ If yes, by whom?
Was electric log made? Yes ☐ No ☐ If yes, attach copy to this report

(12) WELL LOG: Total depth ft. Depth of completed well ft.
from ft. to ft. Formation (Describe by color, character, size or material)

Work started 19 Completed 19

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED
(Well Driller)
NAME
(Person, firm, or corporation) (Typed or printed)
Address
City Zip
License No. Date of this report

CONFIDENTIAL
NOT FOR PUBLIC USE
WATER CODE SEC. 13752

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

Fig. 3.29 Water well drillers' report
(Permission of California Department of Water Resources)

SAMPLE RECORD OF PUMP INFORMATION

Owner ____________________

Pump purchased from ____________________

Pump installed by ____________________

Well Number __________ Date pump installed ____________________

Pump: Make ____________ Type ____________________

Model ____________ Serial No. ____________________

Pump performance curve number ____________________

Bowl diameter __________ Capacity __________ Total head ________

Number of bowls ________ Depth of setting ____________________

Column diameter ________ Shaft diameter __________ Length ________

Length of strainer or tailpipe ________ Length of airline ________

Motor: Make ____________ Type ____________________

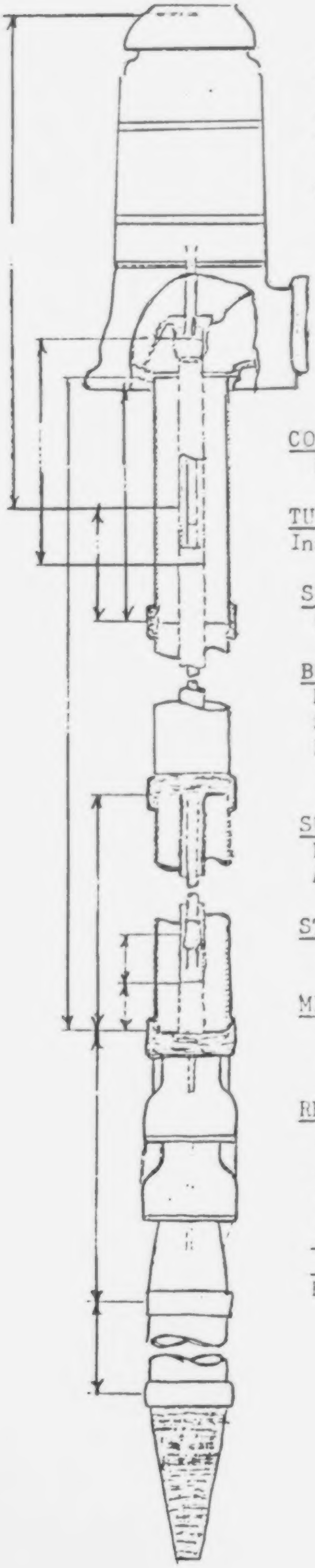
Model ____________ Serial No. ____________________

Horsepower ____________ RPM ____________________

Voltage ________ Phase __________ Cycles ____________________

REPAIR RECORD		
Date	Type of Repairs	Repairs made by

Fig. 3.30 Sample record of pump information



Well No. ____

Location ____

MOTOR Cat. No ____ Date ____
Serial ____ Frame ____ Thr Brg. ____ Oil Cap. ____
City Inv. No. ____ Mfg. ____ HP ____ Rad.Brg. ____ Oil Cap ____
Voltage ____ MPM ____ Make ____ Type ____
Type of Shaft ____ Weatherproof Yes ____ No ____ Drive Nut Thd. ____

HEAD Cat. No. ____
Mfg. ____ City Inv. No. ____ Serial No. ____
Col. Size ____ Max. Col. Size ____ Col. Bolt Cir ____
Disch. Size ____ Disch. Bolt Cir. ____
Tension Nut Type ____ Thd. ____

COLUMN
Diameter ____ Type of Thread ____

TUBE
Inside Dia. ____ Type of Thread ____

SHAFT
Outside Dia ____ Type of Thread ____

BOWLS Cat. No. ____
Mfg. ____ Size or Type ____ No. Stages ____
Serial No. ____ Impeller O.D. ____
Performance Curve No. ____ Pump Level ____
Draw Down ____ Capacity ____ GPM at ____

SUCTION
Diameter ____ Type of Thread ____
Adapter ____ X ____

STRAINER
Size ____

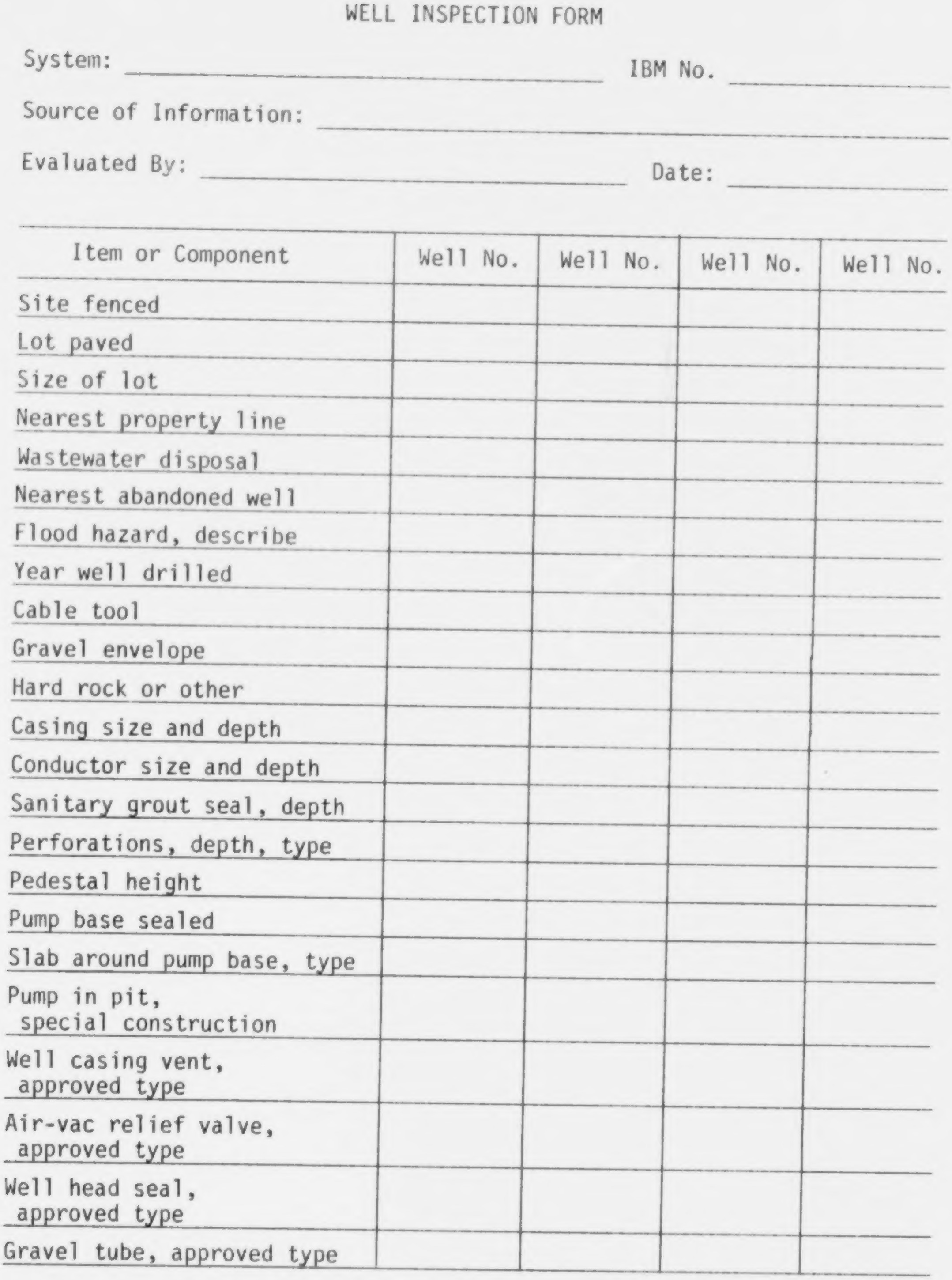
AIR LINE
Length ____

MISCELLANEOUS
Well Dia. ____ Sounding Depth ____ S.W.L. ____
Spiders At ____ Joints

REMARKS ____

Pulled By ____ Installed By ____

Fig. 3.31 Sample record of well pump
(Source: City of Phoenix, Arizona)



WELL INSPECTION FORM

System: ____________________ IBM No. __________

Source of Information: ____________________

Evaluated By: ____________________ Date: __________

Item or Component	Well No.	Well No.	Well No.	Well No.
Site fenced				
Lot paved				
Size of lot				
Nearest property line				
Wastewater disposal				
Nearest abandoned well				
Flood hazard, describe				
Year well drilled				
Cable tool				
Gravel envelope				
Hard rock or other				
Casing size and depth				
Conductor size and depth				
Sanitary grout seal, depth				
Perforations, depth, type				
Pedestal height				
Pump base sealed				
Slab around pump base, type				
Pump in pit, special construction				
Well casing vent, approved type				
Air-vac relief valve, approved type				
Well head seal, approved type				
Gravel tube, approved type				

Fig. 3.32 Well inspection form

Item or Component	Well No.	Well No.	Well No.	Well No.
Sampling tap, approved type				
Type of meter				
Type pump, HP				
Pump capacity, GPM				
Pump setting				
Lubrication, oil or water				
Power, electric or gas				
Auxillary power, gearhead/generator				
Pump control				
Pressure range, psi				
Frequency of use				
Pump discharges to -				
Pressure tank, capacity				
Pressure relief valve				
Pressure tank drains to -				
Air release valve discharge				
Air charger, approved type				
Housing type				
Floor material				
Housekeeping				
Chemicals fed at well				
Chemical application point				
Well records maintained				
Pump efficiency tests				
Well log				
Water level measured				

Fig. 3.32 Well inspection form (continued)

Wells drilled in alluvial formations where the water-bearing aquifers consist of numerous layers of sand and gravel deposits are susceptible to sand production. In many localities, formations of sand and gravel are the only water-bearing formations of sufficient yield available to a community. Properly designed and constructed wells can be drilled in these types of formations that produce high yields while at the same time are virtually sand free. A carefully designed gravel envelope well, with selected louvers or well screen, supported by an engineered filter pack, should operate many years without producing any significant quantities of sand. However, the typical perforated casing or open-bottom well that has penetrated water-bearing sand formations is likely to produce sand.

Some wells produce sand from the very beginning while others may be in use for some length of time before it is evident that the quantity of sand produced by the well is causing problems.

3.71 Problems Associated With Sand

The abrasive action of sand can damage well pumping facilities, consumers' fixtures and appliances, water meters, and precision equipment. In addition, sand can accumulate in the mains in the distribution system, thereby reducing their carrying capacity and increasing friction loss. Sand can also be carried into the consumers' premises with resultant complaints.

Excessive sand production from a well could create cavities in the water-bearing formations and result in the eventual collapse of unstable overlying strata (layer of soil) and damage to the well.

Tests have demonstrated that it is the sand particles larger than 200 mesh (74 microns) that cause the most trouble. Almost all sand contained in well water is this size or coarser.

Several methods are available to the well system operator to reduce sand production to an acceptable level. One method is to install a sand separator designed to remove the objectionable sand and other solids from the well water. Another method would be to pump the well at various rates of flow to determine if a lower rate of flow would reduce the amount of sand to an acceptable level. Many times a small change in water production will make a large change in sand production. In addition, if the system hydraulics permit, the well or wells producing objectionable amounts of sand could be operated on a continuous basis by either raising the cut-off pressure, or preferably, by controlling the operation of the well pump by means of a time clock. An alternate, and perhaps less desirable, approach would be to keep the sand-producing well in an emergency or stand-by mode. This can be done by setting the cut-in (start) and cut-off (stop) pressure ten pounds (psi) below the other pumps in the system.

If sand production from a well cannot be controlled by the methods described, then rehabilitation of the well or eventual abandonment may be necessary.

Many water utilities have adopted new well specifications that define a sand-free well as one having a sand content of less than five milligrams per liter. This is measured by a properly located Rossum sand tester when it is surged and pumped at 1,000 gallons per minute (63 liters/sec). An alternate to this specification would be a sand content of less than five milligrams per liter for a ten-minute period after the well pump starts.

3.72 Flushing Mains[35]

Numerous factors must be considered when a flushing program is established, such as hydraulic gradient from sources of supply, size of mains within the distribution system, location of main line valves, location of flushing outlets, and the ability to be able to dispose of large quantities of water in a short period of time.

Generally speaking, the majority of sand complaints are usually associated with smaller mains and dead end lines. Repeated flushing of small diameter mains may be ineffective and costly. Sand problems associated with small mains may originate from the larger mains supplying them; unless the larger mains are adequately flushed, sand complaints are likely to continue from consumers served by the small mains.

Available data suggests that flushing velocities should be at least five feet per second (1.5 m/sec) or higher, and the total volume of water flushed should be ten times the volume of the main. Velocities in this range are more readily obtainable in smaller mains, but may be difficult to achieve in larger mains unless special flushing outlets are provided.

The flushing guidelines shown in Table 3.3 are for each 1,000 feet (300 m) of water main and are based on a velocity of five feet per second (1.5 m/sec).

TABLE 3.3 FLUSHING GUIDELINES

Main Size in Inches	Flow in GPM	Flushing Time in Minutes	Volume of Water to Dispose of in Gallons
4	220	30	6,000
6	450	30	13,500
8	775	30	23,250
10	1,225	30	36,750
12	1,750	30	52,500

Flushing techniques and procedures should be tailored to the characteristics of the distribution system. In order to obtain the desired velocity of 5 ft/sec (1.5 m/sec) or more, it may be necessary to alter the normal water flow to a problem area by closing off selected valves and concentrating the flow in a given section of main. If the sand problem area is extensive, flushing should start on the source side of the problem area and progress towards the extremities of the distribution system.

Several minutes of flushing may be required before there is any noticeable amount of sand, but once sand is observed, the flushing operation should continue as long as sand is evident, even if the time period exceeds the 30 minute criterion shown in column three of the guideline (Table 3.3). In other words, don't shut off a flushing outlet if any significant amount of sand is present unless there is danger of flooding property. Where it is not possible to dispose of the entire quantity of water needed, it is more effective to flush at the required velocity for a shorter period of time than it is to reduce the velocity.

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[35] *See Chapter 5, "Distribution System Operation and Maintenance," in WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE for additional information on how to flush water mains.*

3.73 Test For Sand, Volumetric Method

Numerous devices are available for collecting sand samples, such as settling basins, filtration units, and centrifugal separators. The most frequently used device is the centrifugal sand separator which is designed for continuous sampling.

The centrifugal sand sampler most often used for evaluating new wells and monitoring existing wells is the Rossum sampler developed in the early fifties by Mr. John R. Rossum, Engineer of Sanitation for the California Water Service Company. Mr. Rossum's work on the quantitative measurement of sand and his theoretical and experimental investigations of hydraulic transportation of sand through water mains have become a standard in the water utility field. The Rossum sand sampler is illustrated in Figure 3.33.

The sampler is usually installed on the discharge piping from the well pump. Samples taken immediately downstream from valves, meters, and other fittings that create turbulence are representative if the water velocity is five feet per second (1.5 m/sec) or more. The water enters the sampler tangentially (along the outside edge), and the entrained sand, thrown to the outside by centrifugal force, falls into the graduated tube. The sand-free water flows out through an orifice (opening) in the top of the unit. Flow through the unit is maintained by a flow control valve rated at 0.5 gallons per minute (0.03 liters/sec). Periodically, the graduated tube is checked and the volume of sand recorded, along with the time period the pump has operated. With this information, it is possible to compute the average sand concentration based on the flow through the tester.

Studies conducted by Rossum have shown that the sand concentration is considerably greater when a well is first started than it is after a period of continuous operation. This effect is illustrated in Figure 3.34.

The sand tester is a valuable tool. The tester is used to determine if new wells meet the contract specifications for sand volume. When used as a daily operational tool, any increase in sand production can be readily detected and remedial steps taken before any significant amount of sand enters the distribution system.

3.74 Acceptable Concentrations

Studies have been made that suggest that permissible concentration of sand production from a well should not exceed 0.3 cubic feet per million gallons of water (2.2 cubic centimeters of sand per cubic meter of water) pumped. Sand concentrations above this value will almost always result in sanded meters and consumer complaints. Ideally, the sand concentration should not exceed 0.1 cubic feet per million gallons (0.7 cubic centimeters of sand per cubic meter of water).

3.75 Responding to Complaints

Detailed records should be maintained showing the date and location of sand complaints, including estimated concentrations. From this record, you can establish a routine flushing program to flush these problem areas before sand builds up to a nuisance level.

When flushing is necessary, notify consumers in the immediate area not to use water during this flushing period.

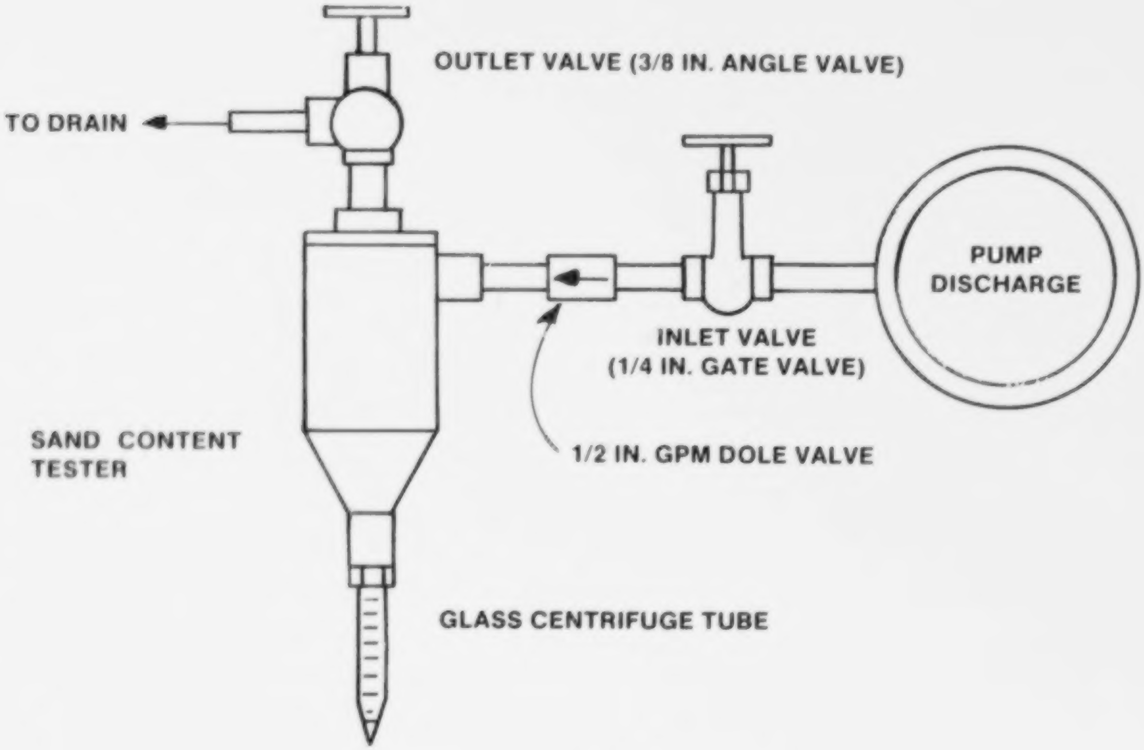

Fig. 3.33 Rossum sand sampler

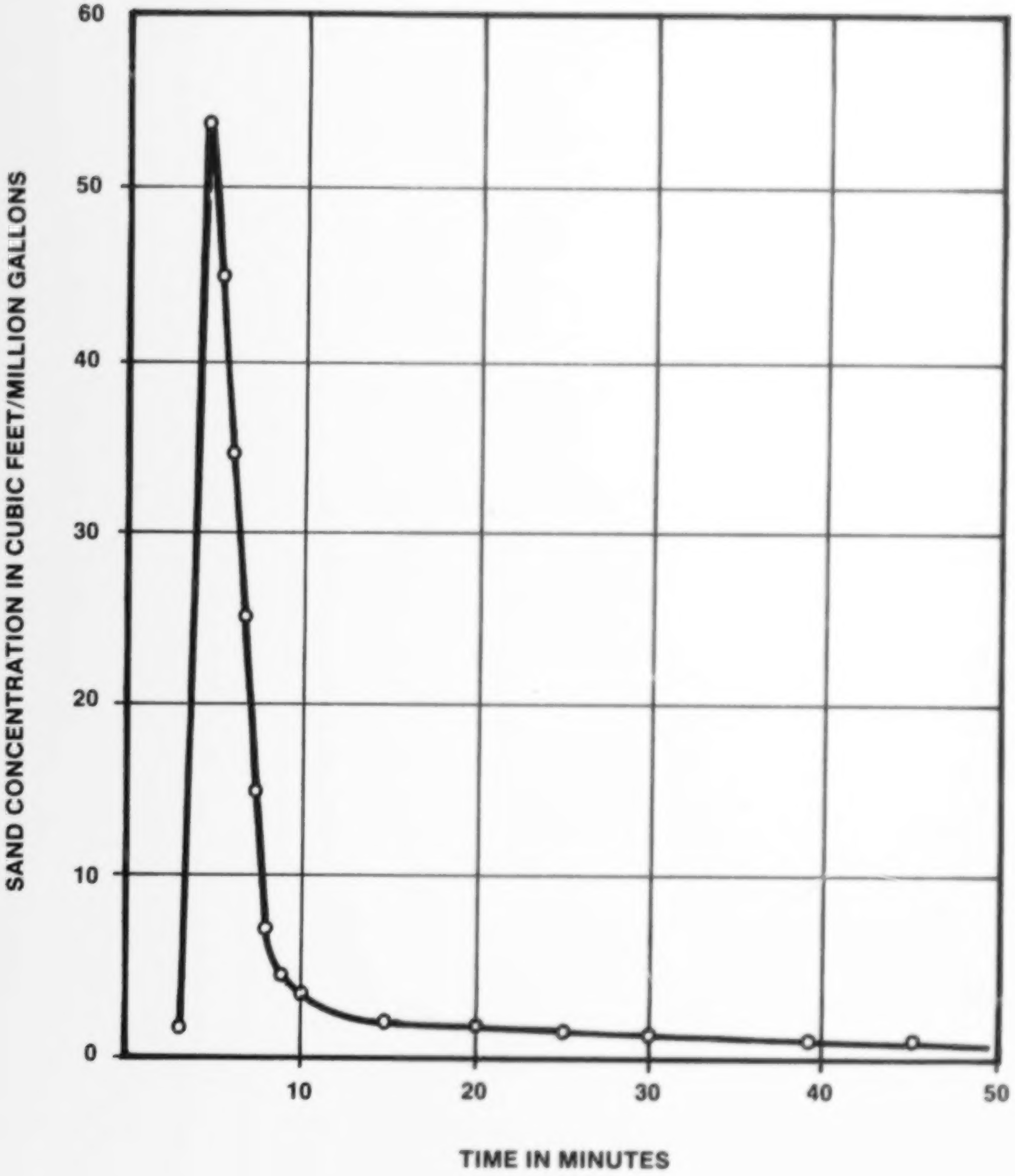

Fig. 3.34 Sand concentration at start of pumping

Heavy concentrations of sand in suspension could be drawn into the consumers' premises causing malfunction of appliances, fixtures damage, plugging of lawn sprinklers, and numerous other problems leading to additional complaints and call backs.

Sand complaints may be isolated to only one or two residences in a block. This condition can occur if the consumer's service lateral is tapped into the side of the main near a fitting or valve which creates turbulence. This type of situation can generally be corrected by relocating the tap at or near the top of the main.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 117.

3.7A How can a well in a sand formation be constructed so that it will be almost sand free?

3.7B What problems are associated with sand in well water?

3.7C The majority of sand complaints concern what part of the distribution system?

3.7D How long should a flushing operation be continued?

3.7E What is the permissible concentration of sand in water from a well?

3.8 ELECTRICAL SUPPLY AND CONTROLS

3.80 Purpose of Electrical Supply and Controls

Control, reduced to its basic definition, is the influence over the action of a device resulting from the measurement and decision of another device or control.

Many options are available for electrical and electronic control of well production. These range from a simple manual start/stop system to automated facilities complete with recorded drawdown and water quality analysis. In this section, we will limit our discussion to the most common and useful types of controls and automation.

3.81 Electrical Supply

3.810 Electricity

Electricity is normally supplied as an alternating current (A.C.) at 120, 240, or 480 volts. The voltage is considered the driving force and quite often the amount of voltage available depends upon the location of the well installation and the ability of the utility company to provide power. The voltage required is related to the size of the pump; larger motors require higher voltages. High horsepower (HP) motors may require large surges of power at start-up.

3.811 Motor Starters

Motor starters are basically controls for starting and stopping motors. Upon receiving a signal to start, current is fed into the motor causing the pump to run. Starters can be direct, across-the-line types or what is referred to as step starters. In step starters power to the motor is increased slowly (in steps) allowing the pump to come up to speed gradually. A typical across-the-line starter arrangement for a three-phase pump is shown in Figure 3.35.

3.812 Auxiliary Power

Auxiliary power is an important consideration to many water districts. If a water-supply system depends on wells and hydropneumatic pressure tanks for both supply and storage, a power outage could create very severe water shortages. Auxiliary power is not difficult to provide at well sites, but it is expensive. These systems can be installed to start and stop automatically and are quite dependable. A typical gasoline-driven engine-generator is shown in Figure 3.36. There are numerous manufacturers of diesel or gasoline-powered generators and they can be obtained in almost any size.

The manufacturers of auxiliary generators also produce automated control packages, but the most commonly used control device is a time delay starter. If a power failure occurs, a relay will sense the loss of power and drop out. A timer then measures a definite time delay that power is off and, after a predetermined period, the auxiliary engine is activated. Shutdown usually occurs in the same manner.

Although we are not going to describe auxiliary power systems in detail here, they should be an important consideration of any water district. These systems can be a real asset under very adverse conditions.

3.82 Pump Controls

3.820 Types of Controls

There are three major types of pump controls, (1) on-off, (2) proportional, and (3) derivative (sometimes called "reset" or "rate"). Electrical controls fall mostly into the first category. On-off, the simplest form, consists of a measured variable such as the level in a pond, or the pressure in a tank, which upon falling to some pre-set level, closes a switch contact. This engages a motor which drives a pump to increase the level until it reaches a pre-set cut-off point. For most applications, the use of the simple on-off set of controls is quite acceptable, and it has the advantage of being low in cost, has few parts, and is usually very reliable.

As drinking water regulations become more stringent, some form of proportional control will be needed. Proportional control provides more corrective effort as the measured variable gets farther from the *SET POINT.*[38] In the case of the reservoir level, this might mean that as the level gets low, and then lower, several additional pumps may be called upon to pump into it. As the level approaches the desired level, the extra pumps are turned off, and eventually, as it arrives at the set point, all pumps stop. Figure 3.37 shows the typical start/stop arrangement for both on-off and proportional controls.

The derivative or rate controls are used to maintain water levels or pressures within very close tolerances. This type of control is normally coupled with variable-speed motor

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[38] *Set Point. The position at which the control or controller is set. This is the same as the desired value of a process variable or level in a tank.*

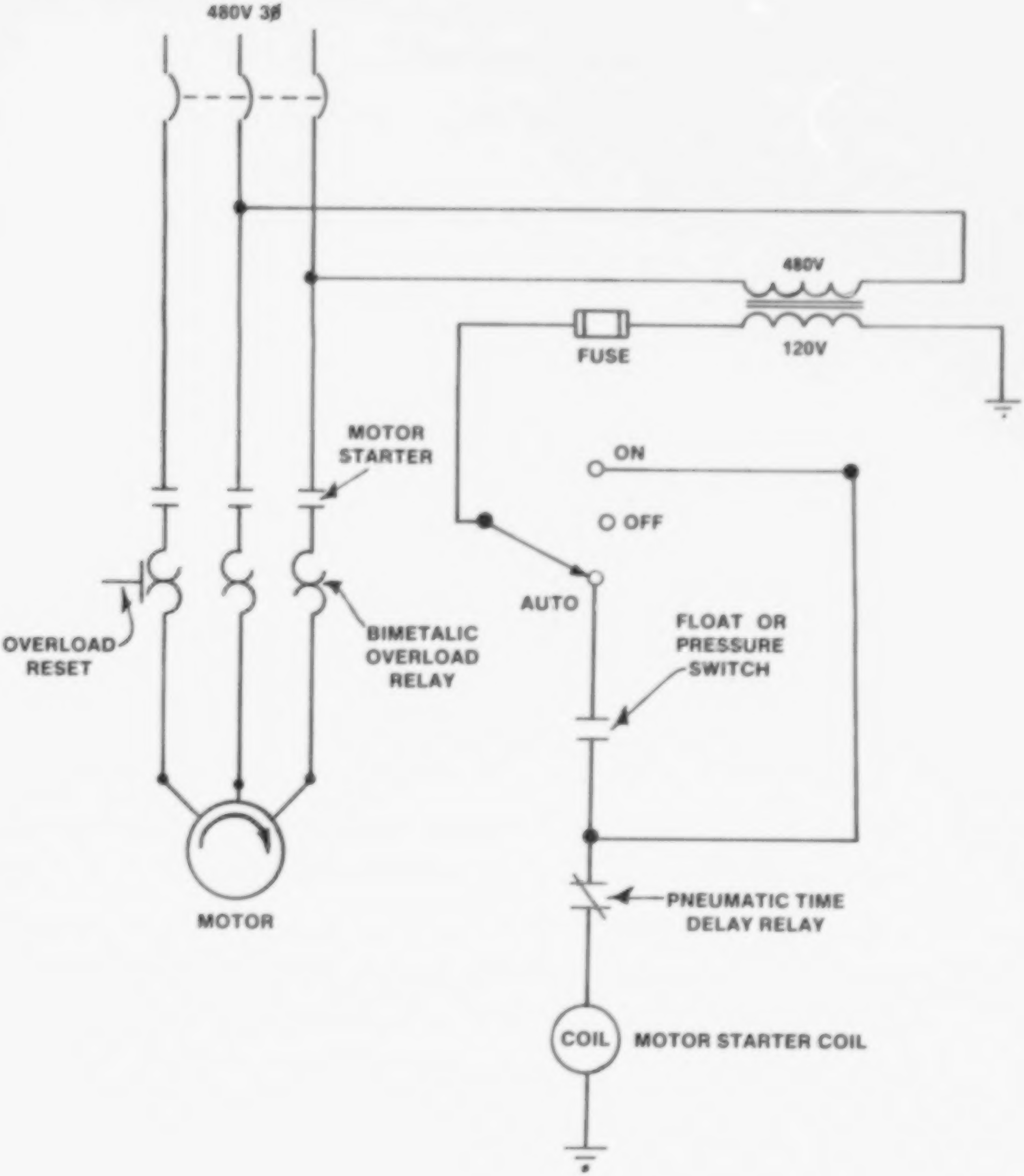
480V 3∅
480V
120V
FUSE
MOTOR
STARTER
ON
OFF
AUTO
OVERLOAD
RESET
BIMETALIC
OVERLOAD
RELAY
FLOAT OR
PRESSURE
SWITCH
MOTOR
PNEUMATIC TIME
DELAY RELAY
COIL
MOTOR STARTER COIL

Fig. 3.35 Schematic of typical 3-phase pump control starter circuit

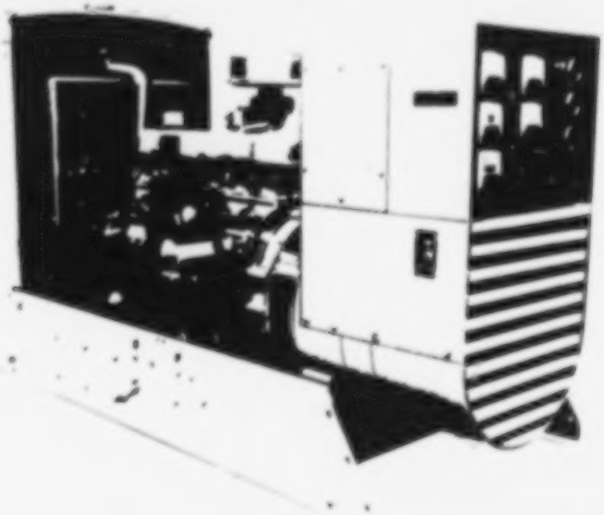

Fig. 3.36 Gasoline-powered auxiliary power generator
(Photo courtesy of Onan Corporation, Minneapolis, Minnesota)

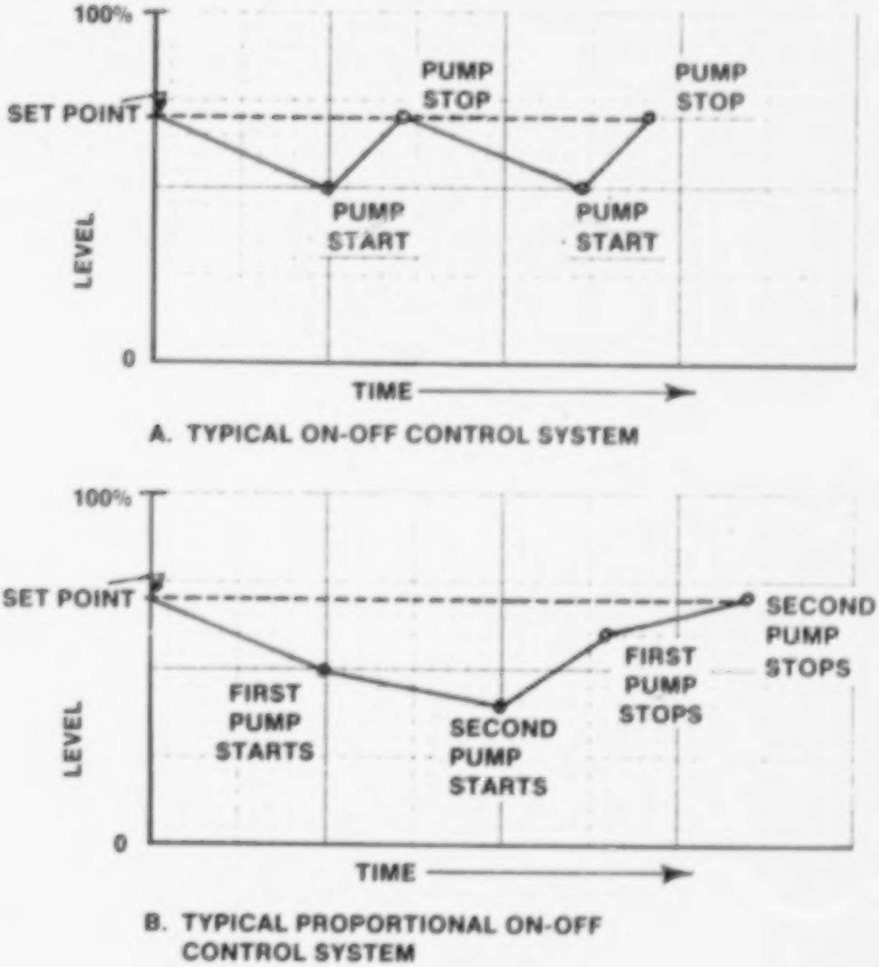

Fig. 3.37 Typical pump start/stop control systems

drives. As the need arises, the controller can cause the pump to increase or decrease its speed to keep water levels or pressures within closely confined limits. Unless the system is highly sophisticated or is restricted by critical operating guidelines, rate controls are seldom used.

3.821 Control Systems

Control systems vary but practically all pumping facilities have some kind of automatic start/stop arrangement. Various pump start/stop sequences are associated with one or more of the following: pressure, water level, time sequences, heat protection, backspin protection, flow and water quality. The control system is quite often coupled with recordings of flow, bearing temperatures, pressure, water levels, and alarms. The two most common pump control elements are pressure and water level.

3.822 Pressure

Pressure is a necessary element of a water system and can easily be monitored at various locations in the system. The most common such pressure regulation system is that associated with hydropneumatic tanks. As a pressure reduction is sensed, a signal is sent to the pumps to start. The subsequent pump start-up pushes water into the system which results in an increase in pressure. Once the desired pressure is reached and sustained for a predetermined length of time, a signal is sent to the pump ordering a shutdown. High or low pressure cut-offs (signals to shut off the pumps if pressure is too high or too low) are common safety features built into the system. These are often coupled with alarms which alert the operator to unusual conditions at the pump. High pressure might indicate valve failure or blockage in the discharge lines. Low pressure would be an indicator of excessive water use or a broken water line. In either case, the automatic pressure controls provide a mechanism for shutting down the pumps until the problem is located and corrected.

3.823 Water Level

The most frequently used pump control system is the water level controller in reservoirs and storage tanks. A sensor measures the water level and signals the pump to start or stop. As the water level is lowered in the tank, the pump is instructed to start. Once the tank has filled, the pump will be ordered to stop. A typical pump control system from a reservoir is shown in Figure 3.38. However, well pump starts/stops can also be controlled by the water level in a well.

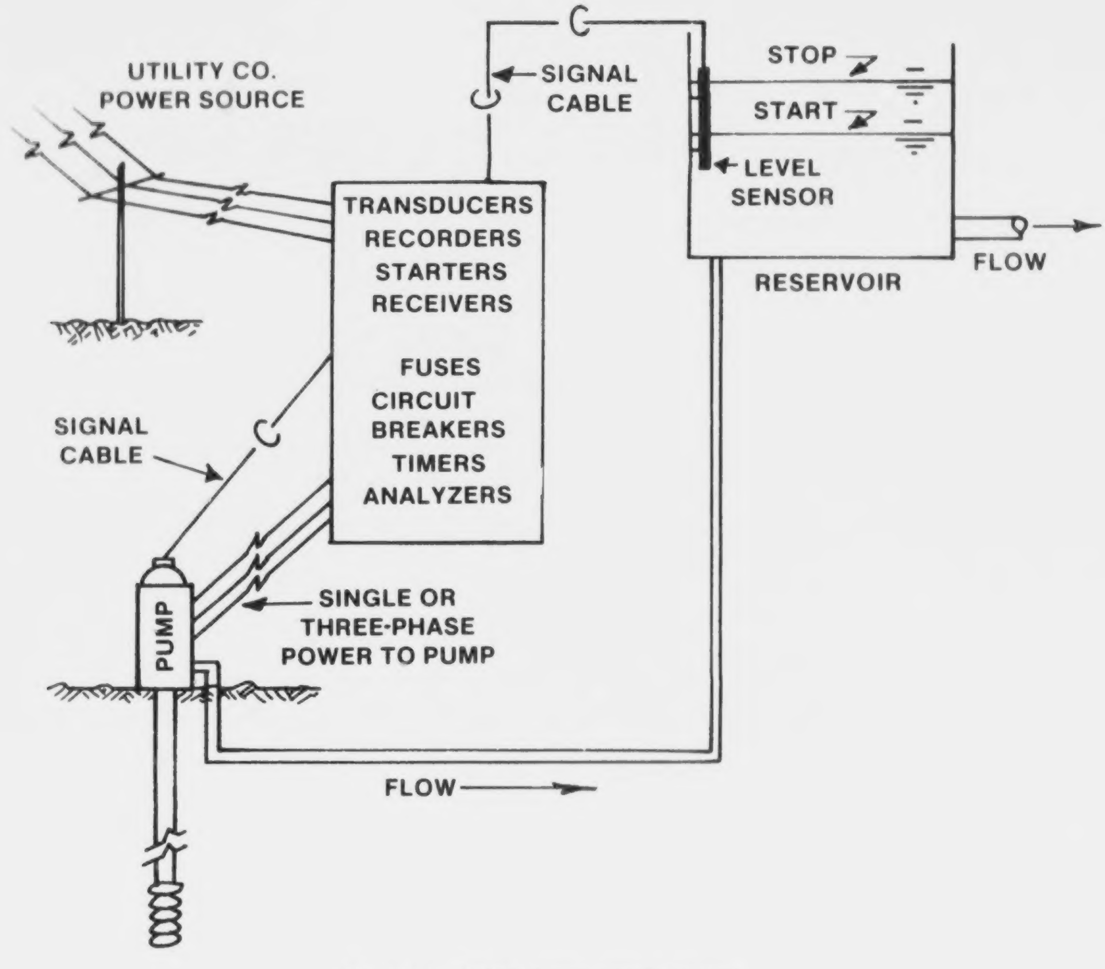

Fig. 3.38 Typical pump control system

In the case of wells, water level operation would only be implemented in the case of low-yield wells that had to be protected from overdraft. Damage to the pumps can occur if the water level is allowed to be drawn below the pump bowls. If low-water level appears to be a real problem associated with a particular well, then some provision for low level shutdown must be made.

Other items that are often monitored or controlled automatically at pump installations are excessive power demand by the pump, bearing heat on the motor and/or pump, turbidity measurements, and flow. Backspin protection[37] is provided for with time delays built into the automatic controls. High head or high volume pumps are sometimes shut down through the use of automatic pump control valves. The total number and combination of controls of pumps is extremely large but automation can provide a high measure of reliability along with lower cost for operation and maintenance.

3.83 Equipment

Control equipment ranges from direct, connected units from tanks to pumps joined by signal wires, to units separated by several miles from the pumps which transmit signals through telephone lines or by radio. Definitions of equipment commonly used in control systems is listed in Section 3.84. Figure 3.39 shows a typical pump control operation.

3.84 Common Electrical Control Definitions

1. *ALARM CONTACT.* A switch that operates when some pre-set low, high or abnormal condition exists.
2. *ANALYZER.* A device which conducts periodic or continuous measurements of some substance, such as chlorine, fluoride or turbidity. Analyzers may operate by any of several methods including photocells, conductivity or complex instrumentation. A pH meter is a type of analyzer.
3. *CONTACTOR.* An electrical switch, usually magnetically operated.
4. *CONTROLLER.* A device which controls the starting, stopping or operation of a piece of equipment.
5. *HEAT SENSOR.* A device which opens and closes a switch in response to changes in the temperature. This device might be a metal contact, or a thermocouple which generates a minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a "temperature sensor."
6. *INTERLOCK.* An electric switch usually magnetically operated. Used to interrupt all (local) power to a panel or device when the door is opened or the circuit is exposed to service.
7. *LEVEL CONTROL.* A float device (or pressure switch) which senses changes in a measured variable and opens or closes a switch in response to that change. In its simplest form, this control might be a floating ball connected mechanically to a switch or a valve such as is used to stop water flow into a toilet when the tank is full.
8. *MEASURED VARIABLE.* A characteristic or component part that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.
9. *PRESSURE CONTROL.* A switch which operates on changes in pressure. Usually this is a diaphragm pressing against a spring. When the force on the diaphragm overcomes the spring pressure, the switch is actuated (activated).
10. *PRIMARY ELEMENT.* An instrument which measures (senses) a physical condition or variable of interest. Floats and thermocouples are examples of primary elements. Also called a SENSOR.
11. *RECEIVER.* A device which indicates the result of a measurement. Most receivers in the water utility field use either a fixed scale and movable indicator (pointer) such as a pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called an INDICATOR.
12. *RECORDER.* A device that creates a permanent record, on a paper chart or magnetic tape, of the changes in some measured variable.
13. *SENSOR.* An instrument which measures (senses) a physical condition or variable of interest. Floats and thermocouples are examples of sensors. Also called a PRIMARY ELEMENT.
14. *SET POINT.* The position at which the control or controller is set. This is the same as the desired value of a process variable or level in a tank.
15. *SOLENOID.* A magnetically (electrical coil) operated mechanical device. Solenoids can be a small valve or a switch.
16. *STARTERS.* Most starters for small motors are "across-the-line" which means that they simply connect the motor terminals to the incoming line. Large motors would impose severe mechanical shock to the driven machine if started this way, as well as creating a severe disturbance to the electrical lines, causing dimming and flickering lights. Therefore, motors over 100 HP (75 kw) are usually started by "reduced voltage" starters or two-step starters The voltage reduction can be accomplished by the use of an auto-transformer with taps that provide 50 percent voltage until the motor and load are moving, then go to full voltage "across-the-line." These can be operated manually, in response to a pair of switches, or automatically in response to motor current or a definite time delay which allows the assembly time to come up to speed.
17. *TIME LAG.* The time required for processes and control systems to respond to a signal or reach a desired level.
18. *TIMER.* A device for automatically starting or stopping a machine or other device at a given time.
19. *TRANSDUCER.* A device which senses some varying condition and converts it to an electrical signal for transmission to some other device (a receiver) for processing or decision making. Flow meters and heat sensors are examples of transducers.
20. *VARIABLE FREQUENCY DRIVE (V.F.D.).* A control system which allows the frequency of the voltage applied to the motor to be varied. The motor is connected to a low frequency source while standing still, and the frequency is increased gradually until the motor and pump, or

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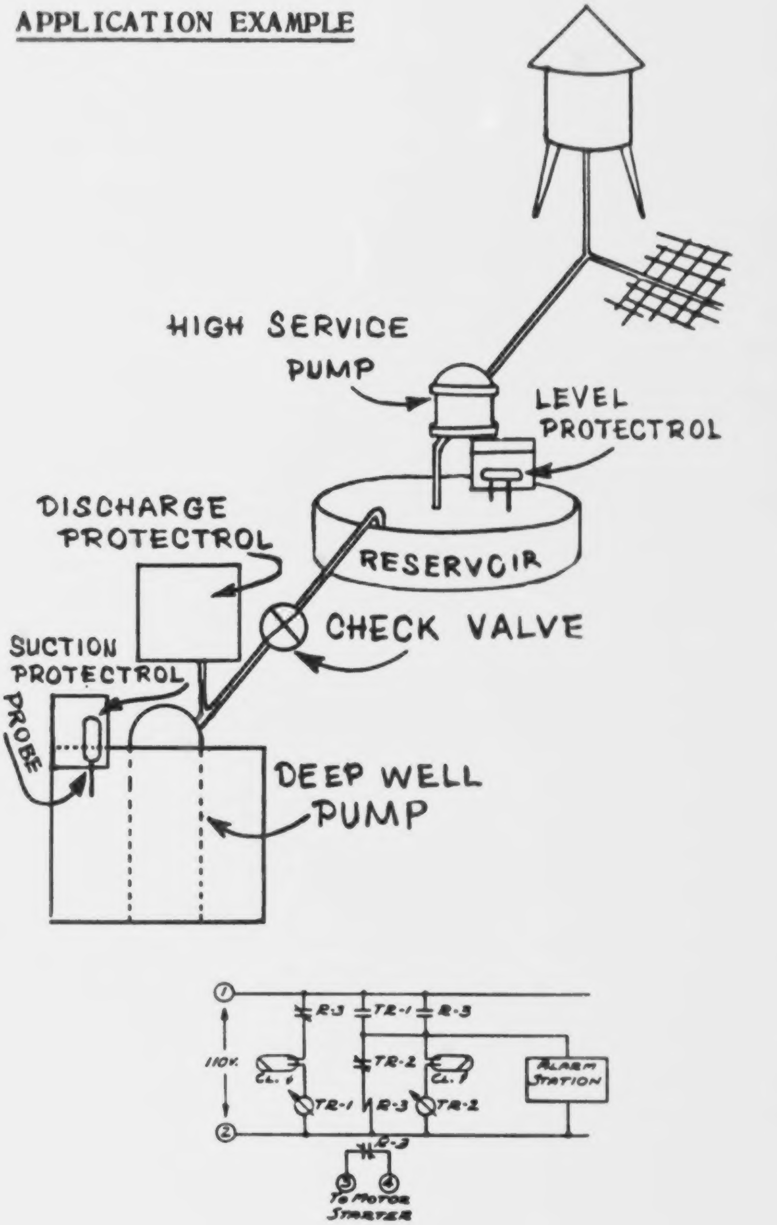
[37] *If pump and motor are restarted while backspinning (water driving pump in reverse), the shaft may break causing expensive repairs. Provision must be made to prevent this from occurring.*


APPLICATION EXAMPLE
HIGH SERVICE PUMP
LEVEL PROTECTROL
DISCHARGE PROTECTROL
RESERVOIR
CHECK VALVE
SUCTION PROTECTROL
PROBE
DEEP WELL PUMP
1
R-3
TR-1
R-3
110V.
CL. 6
TR-2
CL. 1
ALARM STATION
TR-1
R-3
TR-2
2
R-3
3
4
To MOTOR STARTER

Two pressure elements are manifolded and tapped directly into the suction main. If pressure falls to a danger point, the "cutout" element will close its switch, completing the circuit to the timer (TR-1), which begins to time out. If pressure remains low long enough for timer to time out, its contact will close, energizing the relay (R-3). A normally closed relay contact then opens, stopping the pump. When the pressure rises, the "restore" switch closes, energizing the second timer (TR-2). After it has timed out, its normally closed contact will open, de-energizing the relay, allowing the pump to restart if required by primary control.

Fig. 3.39 Typical pump control operation

(Permission of Automatic Control Company) other driven machine, is at the desired speed. This system offers the additional advantage of continuous control of speed, in accord with some measurement.

3.85 Instrumentation

For additional information on controls and instrumentation, see Chapter 19, "Instrumentation," in Volume II, *WATER TREATMENT PLANT OPERATION*, of this series of operator training manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 117.

3.8A The voltage required for a pump depends on what factors?

3.8B Why do large pumps need motor starters?

3.8C List the three major types of pump controls.

3.8D How does a proportional pump control work?

3.9 TROUBLESHOOTING

3.90 Need for Troubleshooting

Approximately 75 percent of well pump and control problems are associated with electricity. The well pump operator should have a good working knowledge of electrical circuits and circuit testing instruments before attempting to service or troubleshoot the electrical circuits and components commonly used in well pump operations. The operator should not undertake any electrically related troubleshooting or repair job until instructions have been received on how to do it properly and until the operator has been authorized to perform that job.

Small water utilities who do not have a knowledgeable operator or electrician on their staff should arrange with a local electrical firm or pump service company to perform this service.

3.91 Troubleshooting Guide

This "Troubleshooting Guide" is designed to assist the operator or service personnel in diagnosing and correcting the most common problems associated with well pumping facilities.

TO USE THE GUIDE:

1. Find the appropriate condition in the SYMPTOM column or section.
2. Find the cause in the PROBABLE CAUSE column.
3. Perform the CORRECTIVE ACTION listed in the third column. The remedy is listed briefly and the procedures may not be detailed enough to cover every possibility.

The operator should not proceed if there is any doubt as to what is meant or what course of action should be taken to correct a given problem. The "Troubleshooting Guide" is on the next two pages.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 118.

3.9A What is the greatest cause of well pump and control problems?

3.9B If you are neither authorized nor qualified to perform electrical repairs, who should do it?

3.9C How would you correct a water-logged hydropneumatic tank?

3.9D What could cause a pump to draw too much power?

3.10 Arithmetic Assignment

Turn to the Appendix at the back of this manual and read the following sections:

1. A.2 Areas,
2. A.3 Volumes,
3. A.10 Basic Conversion Factors,
4. A.11 Basic Formulas, and
5. A.12 How to Use the Basic Formulas.

Check all of the arithmetic in Sections A.2, Areas (A.20, A.21, A.22, A.23, A.24, A.25 and A.26) and A.3, Volumes (A.30, A.31, A.32, A.33 and A.34) on an electronic pocket calculator. You should be able to get the same answers.

3.11 Additional Reading

1. *TEXAS MANUAL*, Chapter 13, "Pumps and Measurement of Pumps."
2. IMPROVING WELL AND PUMP EFFICIENCY, Order No. 20167. Available from Computer Services, American Water Works Association, 6666 West Quincy Avenue, Denver, Colorado 80235. Price to members, $10.00; nonmembers, $22.50.

End of Lesson 4 of 4 Lessons on WELLS

TROUBLESHOOTING GUIDE

SYMPTOM	PROBABLE CAUSE	CORRECTIVE ACTION
3.910 PUMP WILL NOT START	Circuit breaker or overload relay tripped, motor cold.	Reset breaker or reset manual overload relay.
	Fuses burned out.	Check for cause and correct, replace fuses.
	No power to switch box.	Confirm with voltmeter by checking incoming power source, notify power company.
	Motor is hot and overload relay has tripped.	Allow motor to cool. Check supply voltage. If low, notify power company. If normal, reset overload relay, start motor, check amperage; if above normal, call electrician.
	Loose or broken wire, or short.	Tightening wiring terminals, replace any broken wires, check for shorts and correct.
	Low line voltage.	Check incoming power, use voltmeter; if low, notify power company.
	Defective motor.	*MEG*[38] out motor; if bad, replace.
	Defective pressure switch.	With contact points closed, check for voltage through switch; if no voltage, replace switch; if low voltage, clean contact points; if full voltage, proceed to next item.
	Line to pressure switch is plugged or valve in line has accidentally been shut off.	Open valve if closed. Clean or replace line.
	Pump control valve malfunctioning.	Check limit switch for proper travel and contact. Adjust or replace as required.
	Defective time delay relay or pump start timer.	Check for voltage through relay or timer — replace as necessary — check for loose linkage.
	Float switch or transducer malfunctioning.	If pump is activated by float switch or pressure transducer on storage tank, check for incoming signal; if no signal, check out switch or transducer with voltmeter. If OK, look for broken cable between storage tank and pump station.
3.911 PUMP WILL NOT SHUT OFF	Defective pressure switch.	Points in switch stuck or mechanical linkage broken, replace switch.
	Line to pressure switch is plugged or valve in line has been accidentally shut off.	Open valve if closed. Clean or replace plugged line.
	Cut-off pressure setting too high.	Adjust setting.
	Pump control valve malfunctioning.	Check limit switch for proper travel and contact. Adjust or replace as required.
	Float switch or transducer malfunctioning.	Defective incoming signal, check and replace components as required. Check cable.
	Defective timer in pump stop mode.	Check for voltage through pump stop timer, replace if defective.
3.912 PUMP STARTS TOO FREQUENTLY	Pressure switch cut-in and cut-off settings too close.	Adjust settings, maintain minimum 20 psi (138 kPa or 1.4 kg/sq cm) differential.
	Water-logged tank.	Add air to tank. Check air charging system and air release valve. Also check tank and connections for air leaks.
	Leaking foot valve.	Check for backflow into well; if excessive or if pump shaft is turning backwards, correct problem as soon as possible.
	Time delay relay or pump start/stop timers are malfunctioning.	Check relay or timers for proper operation, replace defective components.

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[38] *Meg. A procedure used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring.*

TROUBLESHOOTING GUIDE (Continued)

SYMPTOM	PROBABLE CAUSE	CORRECTIVE ACTION
3.913 FUSES BLOW, CIRCUIT BREAKER OR OVERLOAD RELAYS TRIP WHEN PUMP IS IN OPERATION	Switch box or control not properly vented, or in full sunshine or dead air location, overload relay may be tripping due to external heat.	Provide adequate ventilation (may require small fan). Provide shelter from sun. Paint box or panel with heat reflective paint, preferably white.
	Incorrect voltage.	Check incoming power source. If not within prescribed limits, notify power company.
	Overload relays tripped.	Check motor running amperage, verify that thermal relay components are correctly sized to operating conditions. Repeated tripping will weaken units, replace if necessary.
	Motor overloaded and running very hot.	Modern motors are designed to run hot and if the hand can be held on the motor for 10 seconds without extreme discomfort, the temperature is not damaging. Motor current should not exceed name plate rating. Fifteen percent overload reduces motor life by 50 percent.
3.914 PUMP WILL NOT DELIVER NORMAL AMOUNT OF WATER	Pump breaking suction.	Check water level to be certain water is above pump bowls when operating. If not, lower bowls.
	Pump impellers improperly adjusted.	Check adjustment and lower impellers (qualified personnel only).
	Rotation incorrect.	Check rotation.
	Impellers worn.	If well pumps sand, impellers could be excessively worn thus reducing amount of water pump can deliver. Evaluate and recondition pump bowls if required.
	Pump control valve malfunctioning.	Check limit switch for proper travel and contact. Adjust or replace as required.
	Impeller or bowls partially plugged.	Wash down pump by forcing water back through discharge pipe. Evaluate sand production from well.
	Drawdown more than anticipated.	Check pumping water level. Reduce production from pump or lower bowls.
	Pump motor speed too slow.	Check speed and compare with performance curves. Also check lift and discharge pressure for power requirements.
3.915 PUMP TAKES TOO MUCH POWER	Impellers not properly adjusted.	Refer to manufacturer's bulletin for adjustment of open or closed impellers
	Well is pumping sand.	Check water being pumped for presence of sand. Restrict discharge until water is clear. Care should be taken not to shut down pump if it is pumping very much sand.
	Crooked well, pump shaft binding.	Reshim between pump base and pump head to center shaft in motor quill. Never shim between pump head and motor.
	Worn bearings or bent shaft.	Check and replace as necessary.
3.916 EXCESSIVE OPERATING NOISE	Motor bearings worn.	Replace as necessary.
	Bent line shaft or head shaft.	Check and replace.
	Line shaft bearings not receiving oil.	Make sure there is oil in the oil reservoir and the oiler solenoid is opening. Check sight gage drip rate, adjust drip feed oiler for 5 drops per minute plus 1 drop per minute for each 40 feet (12 m) of column.

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. WELLS

(Lesson 4 of 4 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 118. The problem numbering continues from Lesson 3.

16. What are the general responsibilities of operators of well systems?
17. How frequently should operators make routine service calls to a well pumping facility?
18. What procedures can be followed to reduce sand problems in wells drilled in sand formations?
19. How would you respond to a complaint by a consumer about sand in the water?
20. If a power failure occurs, how are auxiliary power generators started?
21. What are the advantages of on-off pump controls?
22. Why do pumps have low-pressure cut-off controls?
23. What types of problems might an operator encounter when working with pumps?

SUGGESTED ANSWERS

Chapter 3. WELLS

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 58.

3.0A The purpose of a well is to intercept groundwater moving through aquifers and bring water to the surface for use by people.

3.0B Two potential problems that can affect wells are (1) pollution and (2) excessive use (overdraft).

3.0C An operator can protect an aquifer by watching for any construction and other activities that might result in wastes entering the groundwater stream.

3.0D Problems that can be caused by overdraft include

1. Permanent damage to the water storage and transmitting properties of aquifers, and
2. Subsidence of land.

Answers to questions on page 61.

3.0E The hydrologic cycle is the continuous circulation of water on our planet. This cycle is the process of evaporation of water into the air and its return to Earth by precipitation (rain or snow).

3.0F The principal reasons for using groundwater include

1. Generally available in most localities,
2. Well and pumping facilities cost less than surface treatment facilities,
3. Water is clearer and can usually meet turbidity requirements,
4. Conditions for growth and survival of bacteria and virus are unfavorable when compared with surface waters,
5. Mineral content for given well is usually uniform,
6. Temperature is usually constant and lower in summer, and
7. Well supplies are particularly suited to the needs of smaller communities in many areas.

Answers to questions on page 63.

3.1A Openings are installed in the top of the well to provide access to the well for taking water level measurements, permitting entrance or escape of air or gas, adding gravel, or for applying disinfection or chemical cleaning agents.

3.1B The purpose of the well-casing vent is to prevent vacuum conditions inside a well by admitting air into the well during the drawdown period when the well pump is first started. (If vacuum conditions are allowed to develop, contamination may be sucked into the well through a possible defective well or conductor casing, or through the top of the well at the pump base.) The well-casing vent also serves to prevent pressure buildup inside the well casing by allowing excess air to escape during the well recovery (refilling) period after the well pump shuts off.

3.1C The water level in a well is determined by inserting a measuring tape into the sounding tube, lowering it down the tube to the water level, and recording the distance. Or, an airline may be used; the pressure necessary to force water out of the line is recorded and converted to feet. Then,

$$\text{Distance Down to Water Surface, ft} = \text{Length of Line, ft} - \text{Water Depth in Line, ft}$$

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 67.

3.2A Check valves act as an automatic shutoff valve when the pump stops to prevent draining of the system or the tank being pumped to, and to prevent pressurized water from flowing back down the pump column into the well.

3.2B A check valve must (1) close watertight, (2) be able to safely withstand hydraulic shock loads, (3) have a low head loss, and (4) be equipped to close the valve disc in advance of flow reversal.

3.2C Pump control valves serve to eliminate line surge when the pump is started and stopped.

3.2D Flows must be known in order to calculate the correct chemical feed rate.

Answers to questions on page 68.

3.2E Sand particles should be prevented from entering the distribution system because sand particles can cause (1) reduced pump efficiencies due to worn impellers, (2) sanded water mains, (3) excessive meter wear and plugging, (4) wearing of household plumbing fixtures and appliances, and (5) customer complaints.

3.2F Sand traps are not recommended for the removal of sand from well water because they are costly and inefficient.

3.2G Most sand separators are relatively effective in removing fine sand, scale, and similar materials from water.

3.2H The interior surfaces of tanks are painted to (1) extend the useful life of the tank, (2) prevent discolored water from entering the distribution system, and (3) to facilitate in the cleaning of the tank.

3.2I Sanitary hazards associated with sand separators or sand traps are generally limited to the discharge system from the accumulator tank and the sand disposal basin or structure.

Answers to questions on page 72.

3.2J Booster pumps are installed to pump a smaller amount of water to a pressure zone that operates at a much higher pressure or elevation than the main well pump system.

3.2K Surge suppressors are installed to absorb shock waves in the fluid (water) system and prevent their transmittal through the line.

3.2L The purpose of an air release/vacuum breaker valve is to (1) exhaust large quantities of air very rapidly from a deep well pump column when the pump is started, and (2) allow air to re-enter the pump column and prevent a vacuum from developing when the pump stops.

3.2M Pressure relief valves should be installed on all hydropneumatic tanks to prevent excessive internal pressures (surge pressures) from causing the tank to explode or rupture.

3.2N Air chargers are used for adding air to a hydropneumatic tank.

3.2O The size of a hydropneumatic tank will depend on the geographic location, pump capacity, peak demand, pump cycling rate, economics, past operational experience, and the amount of property available.

Answers to questions on page 74.

3.3A Three major well maintenance problems are:

1. Overpumping and lowering of the water table,
2. Clogging or collapse of a screen or perforated section, and
3. Corrosion or incrustation.

3.3B Overpumping an aquifer can damage a well by reducing the storage and production capacity of groundwater systems.

3.3C Deposits that develop on well screens include the hard, cement-like form typical of the carbonate and sulfate compounds of calcium and magnesium, the soft, sludge-like forms of the iron and manganese hydroxides, or the gelatinous slimes of iron bacteria. Silt and clay may also be deposited on well screens.

3.3D The use of two or more different types of metals such as stainless steel and ordinary steel, or steel and brass or bronze should be avoided because corrosion is usually greatest at the points of contact of different metals where they come closest to contact.

3.3E Incrusting waters are usually alkaline while corrosive waters are usually acidic.

Answers to questions on page 80.

3.3F Records that should be kept regarding a well include (1) well depth measurements before and after pumping, (2) flow rates, (3) water quality, (4) length of time pumping, and (5) accurate data on pump repairs and causes.

3.3G Surging is a form of plunging which can be used for opening pores in the screen and for cleaning the gravel pack around the screen.

3.3H High-velocity jetting can be used to remove sand from the immediate vicinity of the well screen.

3.3I Incrustation can be removed from the well casing and well by acid treatment.

3.3J Bacterial growths and slime deposits can be removed from well screens by chlorine treatment.

Answers to questions on page 81.

3.3K The chemical quality of groundwater indicates the type of dissolved minerals and will help in the design of a maintenance program if mineral deposition is suspected to be a cause of decreased well performance.

3.3L Downhole video inspection can be used to look for incrustation and/or corrosion of a well screen.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 87.

3.4A Well pumps are generally classified into two basic groups:

1. *POSITIVE DISPLACEMENT* pumps which deliver the same volume or flow of water against any head within their operating capacity, and
2. *VARIABLE DISPLACEMENT* pumps which deliver water with the volume or flow varying inversely with the head (the *GREATER* the head, the *LESS* the volume or flow).

3.4B Advantages of centrifugal pumps include: (1) relatively small space needed for any given capacity, (2) rotary rather than reciprocating motion, (3) adaptability to high-speed mechanisms such as electric motors and gas engines, (4) low initial cost, (5) simple mechanism, (6) simple operation and repair, and (7) safety against damage from high pressure because of limited maximum pressure that can be developed.

3.4C Jet pumps are not commonly installed today because of their low efficiency and the fact that they are being replaced by submersible pumps.

Answers to questions on page 92.

3.4D The three basic purposes of the pump column pipe in a deep-well turbine pumping installation are:

1. Support of the pump in the well,
2. Delivery of water under pressure from the well pump to the surface, and
3. Maintenance of the lineshaft and shaft enclosing (oil) tube assembly in straight alignment.

3.4E Prime movers used with right-angle gear drives include electric motors and gasoline, natural gas, diesel, or propane-powered engines.

3.4F Deep-well turbine oil-lubricated pumps are lubricated by an automatic electric oiler system that is activated by means of an electric solenoid valve when the well pump starts. The needle valve is adjusted to feed the necessary drops of oil per minute for the appropriate column length.

Answers to questions on page 93.

3.5A During the drilling of new wells, contamination could be introduced into the well from the drilling tools and mud, make-up water, topsoil falling in or sticking to tools, and from the gravel itself.

3.5B Disinfection of a well should take place following development, testing for yield, and before the test pump is removed from the well, or when there is evidence of contamination.

3.5C When disinfecting a well, the desired chlorine concentration in the well casing is 50 mg/*L*.

3.5D Special disinfection methods may be required for existing wells because during repair work deposits of slime, bacterial growth, and other debris are dislodged from the inside surfaces of the well casing and from the outside surfaces of the well pump column pipe. These deposits generally settle to the bottom of the well, but some are also smeared on the inside surfaces of the well casing, particularly above the water line which require swabbing of the inside of the well casing.

3.5E If repeated attempts to disinfect a well are unsuccessful, a detailed investigation to determine the cause or source of the contamination should be undertaken.

Answers to questions on page 94.

3.5F

Known		**Unknown**
Casing Diameter, in	= 12 in	Chlorine Required
Casing Length, ft	= 200 ft	
Chlorine Compound, mg/*L* (Sodium Hypochlorite)	= 52,500 mg/*L*	

1. Find the chlorine required from Table 3.2 for a 12-inch diameter well casing when using sodium hypochlorite.

   Table 3.2 Volume = 5 pints

2. Calculate the pints of sodium hypochlorite required.

$$\begin{aligned}\text{Chlorine Required, pints} &= \frac{(\text{Table 3.2 Value})(\text{Casing Length, ft})}{100\text{ ft}}\\ &= \frac{(5\text{ pints})(200\text{ ft})}{100\text{ ft}}\\ &= 10\text{ pints}\end{aligned}$$

ANSWERS TO QUESTIONS IN LESSON 4

Answers to questions on page 96.

3.6A Poor operation and neglect could be one reason why properly designed and constructed well pumping stations fail to produce water in sufficient quantity and quality to meet the needs of the entire community.

3.6B When entering a pumping facility for an inspection, the operator should (1) *LISTEN* for any unusual noises, (2) *FEEL* for vibrations on pieces of equipment, and (3) *LOOK* for anything unusual. A pumping facility inspection form should be completed during the inspection.

3.6C Areas that should be covered by recordkeeping include (1) new construction records, (2) equipment records, and (3) repairs and modifications.

Answers to questions on page 106.

3.7A A well in a sand formation can be constructed so that it is sand free by properly constructing a gravel envelope, with selected louvers or well screen, and supported by an engineered filter pack.

3.7B The abrasive action of sand can damage well pumping facilities, consumers' fixtures and appliances, water meters, and precision equipment. Also, sand can reduce the carrying capacity of water mains and cause consumers to complain.

3.7C The majority of sand complaints are usually associated with smaller mains and dead end lines.

3.7D Flushing operations should be continued as long as sand is evident in the water.

3.7E The permissible concentration of sand in water from a well is 0.3 cubic feet per million gallons of water pumped and 0.1 cu ft per million gallons is the desirable value.

Answers to questions on page 112.

3.8A The voltage required for a pump depends on the size (motor horsepower) of the pump.

3.8B Large pumps need motor starters so the power is induced gradually (in steps) into the motor allowing the pump to come up to speed gradually. This prevents pump damage and disturbances along electrical lines.

3.8C The three major types of pump controls are (1) on-off, (2) proportional, and (3) derivative (sometimes called "reset" or "rate").

3.8D Proportional pump control provides more corrective effort as the measured variable gets farther from the set point. In the case of reservoir level, this might mean that as the level gets low, and then lower, several additional pumps may be called upon to pump into it. As the level approaches the desired level, the extra pumps are turned off, and eventually, as it arrives at the set point, all pumps stop.

Answers to questions on page 112.

3.9A Approximately 75 percent of well pump and control problems are associated with electricity.

3.9B Electrical repairs should be done by someone who is authorized and qualified to do the job. Small water utilities may have to make arrangements with a local electrical firm or pump service company to perform this service.

3.9C To correct a water-logged tank, add air to tank. Also check air charging system, air release valve, and tank and connections for air leak.

3.9D Causes of a pump drawing too much power include:

1. Impellers not properly adjusted,
2. Well is pumping sand,
3. Crooked well causing pump shaft binding, and
4. Worn bearing or bent shaft.

OBJECTIVE TEST

Chapter 3. WELLS

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True-False

1. A polluted groundwater supply may not be acceptable for use for years even if the sources of pollution are eliminated.
    1. True
    2. False
2. Pollution is not a problem for groundwaters because water moving through soil purifies itself.
    1. True
    2. False
3. An air-gap device may be used to provide backflow protection for drinking water.
    1. True
    2. False
4. Adding air to a hydropneumatic tank by means of a portable air compressor can be very time-consuming and costly.
    1. True
    2. False
5. Check valves are commonly installed on the suction side of a centrifugal pump.
    1. True
    2. False
6. The rated capacity of a pump is an accurate measure of water delivery.
    1. True
    2. False
7. Well performance can be affected by the quality of groundwater.
    1. True
    2. False
8. Incrustation results in the destruction of metal.
    1. True
    2. False
9. Pump bowl assemblies with ten or more stages are not recommended.
    1. True
    2. False
10. Many times a small change in water production will make a large change in sand production.
    1. True
    2. False
11. The health and safety of the water users is dependent on good operation of the water supply system.
    1. True
    2. False
12. Auxiliary power is not difficult to provide at well sites, but it is expensive.
    1. True
    2. False
13. Water level controls are the most frequently used control devices for starting and stopping pumps.
    1. True
    2. False
14. Right-angle gear drives provide positive power transmission from a vertical prime mover to a horizontal shaft.
    1. True
    2. False
15. In a multi-stage pump, the function of each stage is to add volume or flow capacity.
    1. True
    2. False

Multiple Choice

16. In order for an operator to preserve and maintain a groundwater supply source, the operator must
    1. Be careful not to overtax the capability of aquifers to supply water.
    2. Be on the lookout for any possible sources of pollution of groundwater.
    3. Develop a recordkeeping program of well production and water quality.
    4. Develop and implement a safety program.
    5. Meet standards specified in the Safe Drinking Water Act.

17. Potential sources of groundwater pollution include
    1. Mining operations.
    2. Septic tanks.
    3. Solid waste sites.
    4. Subsurface leaching systems.
    5. Wastewater collection facilities.

18. The important features of any check valve are that the valve
    1. Be able to safely withstand hydraulic shock loads.
    2. Be capable of regulating flow.
    3. Close the valve disc in advance of flow reversal.
    4. Have a low head loss.
    5. Must close watertight.

19. Toxic materials may gain entry to a well through
    1. A hydropneumatic tank.
    2. Leakage directly into the zone of influence.
    3. Poor well construction.
    4. Pump discharge.
    5. Unprotected openings.

20. Indications of corrosive water include high concentrations of
    1. Algae odors.
    2. Carbon dioxide.
    3. Carbonate.
    4. Total dissolved solids.
    5. Rotten-egg odors.

21. Different types of flow meters include
    1. Electronic sensor.
    2. Orifice plate.
    3. Positive displacement.
    4. Propeller.
    5. Turbine.

22. Wells that require disinfection include
    1. Contaminated wells.
    2. Existing wells—after positive bacteriological test results.
    3. Existing wells—after well or pump repairs.
    4. New wells—after construction.
    5. New wells—before removal of test pump.

23. Methods available for cleaning a well screen include
    1. Acid treatment.
    2. High-velocity jetting.
    3. Rodding.
    4. Scrubbing.
    5. Surging.

24. The concentration of chlorine most commonly used to disinfect a well is
    1. 1 mg/L.
    2. 5 mg/L.
    3. 10 mg/L.
    4. 25 mg/L.
    5. 50 mg/L.

25. Chlorine compounds used to disinfect wells include
    1. Calcium hypochlorite.
    2. Ferric chloride.
    3. Nitrogen trichloride.
    4. Sodium chloride.
    5. Sodium hypochlorite.

26. Possible reasons why a pump will not start include
    1. Circuit breaker relay tripped.
    2. Cut-off pressure setting too high.
    3. Defective motor.
    4. Loose wire.
    5. Low line voltage.

27. Which of the following problems can be created by sand in well waters?
    1. Complaints from consumers
    2. Damage to well by collapse of overlying strata
    3. Incrustations on well screens
    4. Hard water
    5. Reduced capacity of water mains

28. The diameter of the well casing is generally determined by the
    1. Amount of water to be pumped.
    2. Aquifer characteristics.
    3. Corrosiveness of the water.
    4. Distance down to the aquifer.
    5. Safe yield of the well.

29. Possible reasons why a pump will not deliver normal amount of water include
    1. Drawdown more than anticipated.
    2. Impellers worn.
    3. Pump breaking suction.
    4. Pump motor speed too low.
    5. Rotation incorrect.

30. The basic purposes of the pump column pipe in a deep-well turbine pumping installation include
    1. Delivers water under pressure from the well pump to the surface.
    2. Keeps the lineshaft and shaft enclosing tube assembly in straight alignment.
    3. Lubrication of the check valve.
    4. Measures the depth of water in the well.
    5. Supports the pump in the well.

31. Advantages of a centrifugal pump include
    1. Adaptability to low-speed driving mechanisms.
    2. Reciprocating rather than rotary motion.
    3. Relatively small space needed for any given capacity.
    4. Safety against damage from high pressure.
    5. Simple operation and repair.

32. Items that should be included on a pumping facility inspection form include
    1. Air level in tank.
    2. Discharge pressure.
    3. Meter reading.
    4. Name of inspecting operator.
    5. Standing water level.

33. The frequency of routine service calls to a well pumping facility depends on
    1. Availability of manpower.
    2. Hardness of water.
    3. Importance of facility.
    4. Security of facility.
    5. Time of day.

34. Items that may be automatically controlled at pump installations include
    1. Backspin protection.
    2. Bearing heat on the pump motor.
    3. Cone of depression.
    4. Excessive power demand.
    5. Flow.

35. Various pump start/stop sequences may be associated with
    1. Backspin protection.
    2. Heat protection.
    3. Pressure.
    4. Water level.
    5. Water quality.

36. What is the surface area of a rectangular settling basin 50 feet long and 12 feet wide?
    1. 480 square feet
    2. 500 square feet
    3. 540 square feet
    4. 600 square feet
    5. 720 square feet

37. What is the surface area of a circular clarifier 30 feet in diameter?
    1. 706 square feet
    2. 1018 square feet
    3. 1146 square feet
    4. 2827 square feet
    5. 3600 square feet

38. Calculate the volume in cubic feet of a rectangular settling basin 45 feet long, 10 feet wide and 7 feet deep.
    1. 315 cu ft
    2. 450 cu ft
    3. 2460 cu ft
    4. 3150 cu ft
    5. 3500 cu ft

39. Calculate the volume of water in cubic feet in a water-filled well casing 12 inches (1 foot) in diameter and 120 feet long. Select the answer closest to your answer.
    1. 94 cu ft
    2. 113 cu ft
    3. 429 cu ft
    4. 738 cu ft
    5. 1356 cu ft

40. How much sodium hypochlorite is required to dose a well at 50 mg/*L*? The casing diameter is 16 inches and the length of the water-filled casing is 120 feet. Sodium hypochlorite is 5.25 percent or 52,500 mg/*L* chlorine. Select the answer closest to your answer.
    1. 0.8 gallons
    2. 1.0 gallons
    3. 1.2 gallons
    4. 3.0 gallons
    5. 6.0 gallons

End of Objective Test

CHAPTER 3. WELLS

APPENDIX

3.12 WELL SITE SELECTION
3.13 TYPES OF WELLS
3.14 WELL STRUCTURE AND COMPONENTS
3.15 DETERMINATION OF WORKING PRESSURE
3.16 WELL TESTING AND EVALUATION
3.17 PUMP TESTING AND EVALUATION
3.18 ABANDONING AND PLUGGING WELLS

3.12 WELL SITE SELECTION

3.120 Overview

This section is intended to be used as a guideline only. Local county health departments or state health agencies should have sanitary set-back requirements and regulations pertaining to the location of wells in relation to sanitary hazards. *PLEASE CONTACT YOUR LOCAL AUTHORITIES FOR THEIR REQUIREMENTS AND REGULATIONS BEFORE YOU SELECT A SITE AND DRILL.*

3.121 Importance of Site Selection

Perhaps the most important consideration in developing a groundwater source is the selection of the well site. In many cases, wells located too close to sources of contamination must be abandoned and destroyed long before their useful life has been utilized.

Safety of groundwater source depends primarily on three factors: (1) the proper selection of the well site, (2) good well design and construction, and (3) geology. These factors should be the guides used in determining safe distances for different situations. The following guidelines apply only to properly constructed wells. A poorly constructed well is potentially unsafe regardless of the distance from a source of contamination.

The adequate separation of a domestic water supply well away from sources of contamination or pollution is a primary factor in assuring the continued safety of the water produced by the well. Facilities using or transporting hazardous chemicals near a well are objectionable because leakage of contaminants is possible. Such contaminants may gain entry to the well through unprotected openings, poor well design or construction, failure of well casing from corrosion or age, or leakage directly into the zone of influence of the well. These guidelines are for the location of new wells, evaluation of existing wells, and maintenance of sanitary control of future construction in the vicinity of wells. The design and location of a new well should be reviewed with the local health officer or other regulatory authority for approval before construction begins.

3.122 Safe Horizontal Distance

The safe distance of a well from sources of contamination depends upon numerous local factors. To determine the safe distance, evaluate the following factors: (1) character and location of sources of possible contamination, (2) type of well construction, (3) natural *HYDRAULIC GRADIENT*[39] of the water table, (4) permeability of the soil overlying the water-bearing formation, (5) extent of the *CONE OF DEPRESSION*[40] formed in the water table due to pumping the well, and (6) the nature of the soil or rock structure.

3.123 Minimum Horizontal Distance

The minimum safe horizontal distance between a well and potential sources of contamination should be maintained in accordance with Table 3.4 and as shown in Figure 3.40. No lesser distances should be considered unless approved by the local health officer and unless the special protection requirements described in Section 3.125, "Special Construction," are met.

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[39] *Hydraulic Gradient. The slope of the hydraulic grade line. This is the slope of the water surface of the groundwater table or the slope of the water surface in an open channel, or the slope of the water pressure for pipes under pressure.*

[40] *Cone of Depression. The depression, roughly conical in shape, produced in the water table by the pumping of water from a well.*

TABLE 3.4 MINIMUM HORIZONTAL DISTANCE TO WELL[a]

Wastewater Facilities	**Feet**	**Meters**
Septic Tank (Watertight)	50	15
Horizontal Leach Lines	100	30
Seepage Pit or Cesspool	150[b]	45
Pit Privy	50	15
Vault Privy (Pumpout)	50	15
Sanitary Sewers and House Laterals	100[c]	30
Storm Sewers	100[c]	30
Wastewater Pumping Station	100	30
Effluent Discharge Channel	200	60
Drainage Channel	50	15
Wastewater Treatment Plant	*	*
Wastewater Lagoon	*	*
Wastewater Irrigation Area	*	*
Industrial Facilities		
Barnyard, Feedlot, Grazing Area	*	*
Waste Sewers	100[c]	30
Waste Holding (Watertight)	50	15
Petroleum Storage	*	*
Petroleum Transmission	500[d]	150
Solid Waste Disposal Site	**Feet**	**Meters**
Class 1	*	*
Class 2	2,000	600
Class 3	1,000	300
Other		
Dwellings	50	15
Pond, Lake, Stream	100	30
Abandoned Conduit	50	15
Cathodic Protection Well		
Cased	50	15
No Casing	200	60
Abandoned & Destroyed Wells	*	*
Wells Destroyed in Accordance With State or Local Health Department Guidelines	None required	

NOTES:

* Case-by-case evaluation.

[a] *STANDARDS REGARDING LOCATION OF PUBLIC WATER SUPPLY WELLS WITH RESPECT TO SOURCES OF CONTAMINATION OR POLLUTION*, California Department of Health Services, Sanitary Engineering Branch, Berkeley, California.

[b] Bottom of pit should be more than 10 feet above groundwater, preferably separated by an impervious stratum.

[c] See Section 3.125, "Special Construction of Sanitary or Storm Sewers Under Gravity Flow."

[d] Underground storage and transmission facilities should be pressure tested annually.

3.124 Adverse Conditions

In areas where adverse conditions exist, such as coarse gravel formation, lava, fractured or limestone rock, high groundwater, or unusual well construction or topography, the local health officer should approve the well site and the design of the well *BEFORE* construction.

3.125 Special Construction of Sanitary or Storm Sewers Under Gravity Flow

Where 100 feet (30 meters) of separation of the well from a sanitary or storm sewer is not feasible, the sewer should be constructed or reconstructed as specified below.

However in no case should sewers be permitted within 50 feet (15 meters) of any well.

1. The sewer should be constructed of ductile iron pipe — Class 150 — with either rubber ring bell and spigot ends or *MECHANICAL JOINTS.*[41] This type of construction should be adequate under most conditions.
2. Under certain conditions, asbestos-cement pipe — Class 150 — or extra-heavy-wall plastic pipe with rubber ring joints could be used.
3. Special construction methods may be considered on a case-by-case basis. For existing sewers, it may be possible to use a ¼-inch (6 mm) thick continuous steel casing to enclose the sewer pipe. All voids between the sewer pipe and casing must then be pressure grouted with sand-cement grout.
4. The sewer should be of adequate strength to withstand the weight of both backfill and any live load (load from a moving vehicle) that may be imposed on the pipe. The trench should be excavated only to the depth required. This will provide uniform, continuous support for the pipe on solid and undisturbed ground at every point. Any part of the bottom of the trench excavated below the specific grade (such as at the joints) should be corrected with suitable material and thoroughly compacted before the pipe is laid. Backfilling should be accomplished by hand from the bottom of the trench to the centerline of the pipe, using suitable material, placed in layers of three inches (75 mm), and compacted by tamping. The pipe should be pressure tested after installation.

3.126 Sanitary Control of Future Construction

Unless future construction in the vicinity of a well is controlled, the continued use of a well for domestic water supplies may be threatened. The best way to prevent the encroachment of hazardous facilities is by owning enough land around the well to guarantee the required separation whenever possible. Where the utility or water company has limited ownership, it should request notification from the building department, public works, and local wastewater utility agencies of any proposed construction near the well. The water agency will then be assured of an opportunity to suggest modification of any proposed facilities.

3.13 TYPES OF WELLS

There are numerous well construction methods ranging from low-yield, hand-dug wells to high-yield, gravel-envelope wells. Let's briefly review the distinguishing characteristics of wells you are likely to encounter.

3.130 Dug Wells

Dug wells are commonly excavated with hand tools. The excavator descends into the well as the excavation pro-

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[41] *Mechanical Joint. A flexible device that joins pipes or fittings together by the use of lugs and bolts.*

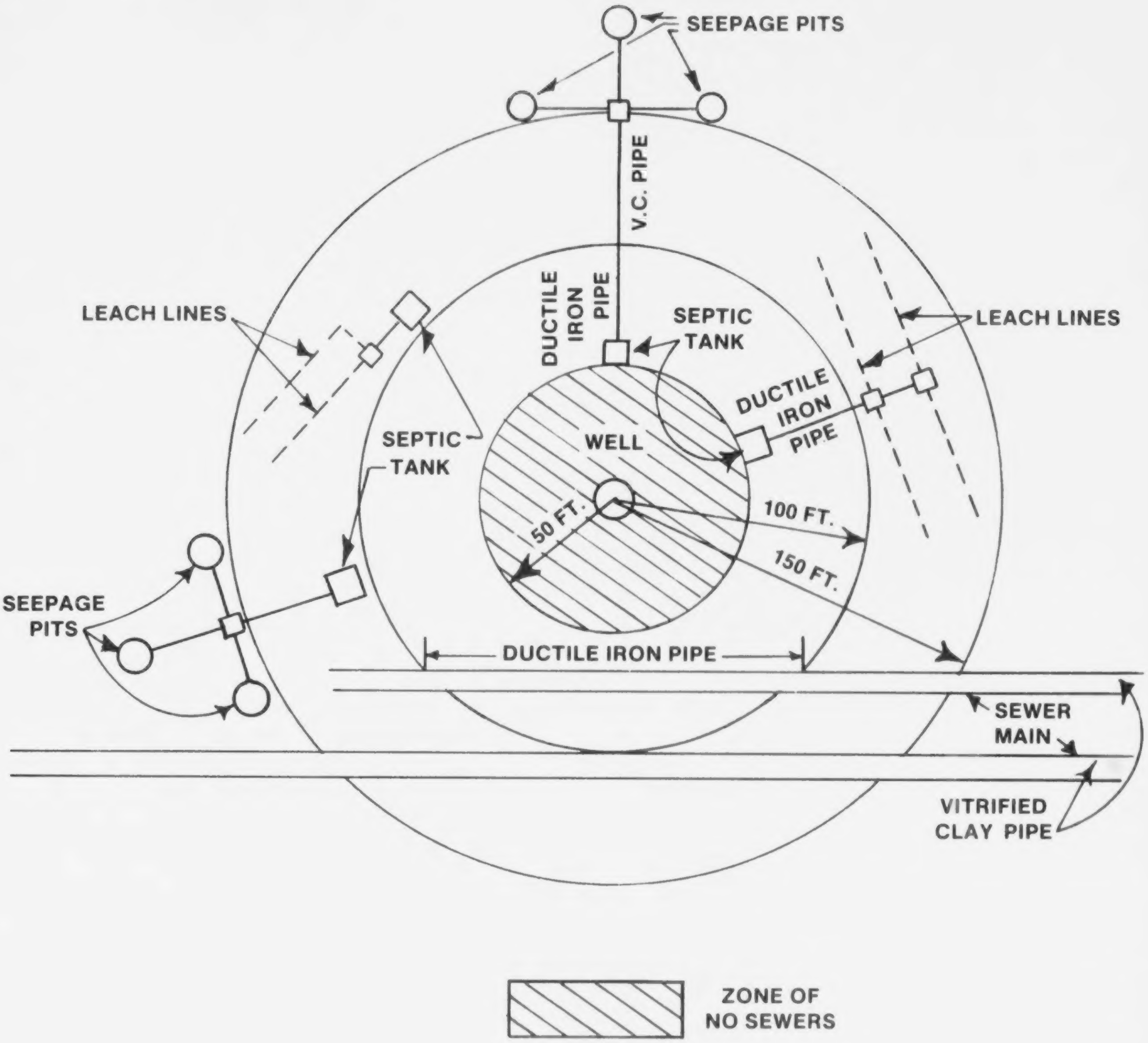
SEEPAGE PITS
V.C. PIPE
DUCTILE IRON PIPE
SEPTIC TANK
LEACH LINES
LEACH LINES
DUCTILE IRON PIPE
SEPTIC TANK
WELL
50 FT.
100 FT.
150 FT.
SEEPAGE PITS
DUCTILE IRON PIPE
SEWER MAIN
VITRIFIED CLAY PIPE
ZONE OF NO SEWERS

Fig. 3.40 Recommended safe distances from a well

gresses. To prevent the native material from caving in, one must place a crib or lining in the excavation and move it downward as the pit is deepened. The space between the lining and the undisturbed embankment should be filled with cement grout down to the water-bearing strata to prevent entrance of surface water along the well lining, (see Figure 3.41). Dug wells usually have a very limited yield and tend to fail in times of drought. Also dug wells are more subject to contamination hazards due to their shallow construction.

3.131 Bored Wells

Bored wells are commonly constructed with earth augers (similar to an oversized drill bit) turned either by hand or by power equipment. Such wells are usually regarded as practical at depths of less than 100 feet (30 meters) when the water requirement is low and the material overlying the water-bearing formation has non-caving properties and contains few large boulders. In suitable material, holes from 2 to 30 inches (50 to 750 mm) in diameter can be bored to about 100 feet (30 m) without caving.

In general, bored wells have the same characteristics as dug wells, but they may be extended deeper into the water-bearing formation due to the fact they are less apt to cave in.

Bored wells may be cased with vitrified clay tile, concrete pipe, standard wrought iron, steel casing, or other suitable material capable of sustaining imposed loads. The well may be completed by installing well screens or perforated casing in the water-bearing sand and gravel. Proper protection from surface drainage should be provided by sealing the casing with cement grout to the depth necessary to protect the well from contamination (see Figure 3.42).

3.132 Driven Wells

The simplest and least expensive of all well types is the driven well. This type of well is constructed by driving into the ground a drive-well point which is fitted to the end of a series of pipe sections (see Figure 3.42). The drive point is of forged or cast steel. Drive points are usually 1¼ or 2 inches (30 to 50 mm) in diameter. The well is driven with the aid of a maul, or a special shafting or falling weight (see Figure 3.43). For deeper wells, the well points are sometimes driven into water-bearing strata at the bottom of a bored or dug well. The yield of driven wells is generally small to moderate. Where they can be driven an appreciable depth below the water table, they are no more likely than bored wells to be seriously affected by water-table fluctuations. The most suitable locations for driven wells are areas containing *ALLUVIAL*[42] deposits of high *PERMEABILITY*.[43] The presence of coarse gravels, cobbles, or boulders interferes with sinking the well point and may damage the sand screen (Figure 3.43) or wire mesh jacket.

3.133 Drilled Wells

Construction of a drilled well is ordinarily accomplished by one of two techniques — percussion or rotary hydraulic drilling. The selection of the method depends primarily on the geology of the site and the preference of the well owner or driller.

3.1330 Percussion (Cable-Tool) Method (Figure 3.44)

Drilling by the cable-tool or percussion method is accomplished by raising and dropping a heavy drill bit and stem. The impact of the bit crushes and dislodges pieces of the formation. The reciprocating motion of the drill tools mixes the drill cuttings with water into a *SLURRY*[44] at the bottom of the hole. This is periodically brought to the surface with a bailer, a 10- to 20-foot-long (3 to 6 m) pipe equipped with a valve at the lower end.

Caving is prevented as drilling progresses by driving or sinking into the ground a casing slightly larger in diameter than the bit. When wells are drilled in hard rock, casing is usually necessary only through the overburden or upper layer of uncompacted material. A casing may be necessary in hard rock formations to prevent caving of beds of softer material.

When good drilling practices are followed, water-bearing beds are readily detected in cable-tool holes because the slurry does not tend to seal off the water-bearing formation. A rise or fall in the water level in the hole during drilling, or more rapid recovery of the water level during bailing, indicates that a permeable bed has been entered. Crevices or soft streaks in hard formations are often water-bearing. Sand, gravel, limestone, and sandstone formations are generally permeable and yield the most water.

3.1331 Hydraulic Rotary Drilling Method

The direct rotary drilling method may be used in most formations. The essential parts of the drilling assembly include a derrick and hoist, a revolving table through which the drill pipe passes, a series of drill sections, a cutting bit at the lower end of the drill pipe, a pump for circulation of drilling fluid, and a power source to drive the drill.

In the drilling operation, the bit breaks up the materials as it rotates and advances. The drilling fluid (called mud) pumped down the drill pipe picks up the drill cuttings and carries them up the *ANNULAR SPACE*[45] between the rotating pipe and the wall of the hole (Figure. 3.45). The mixture

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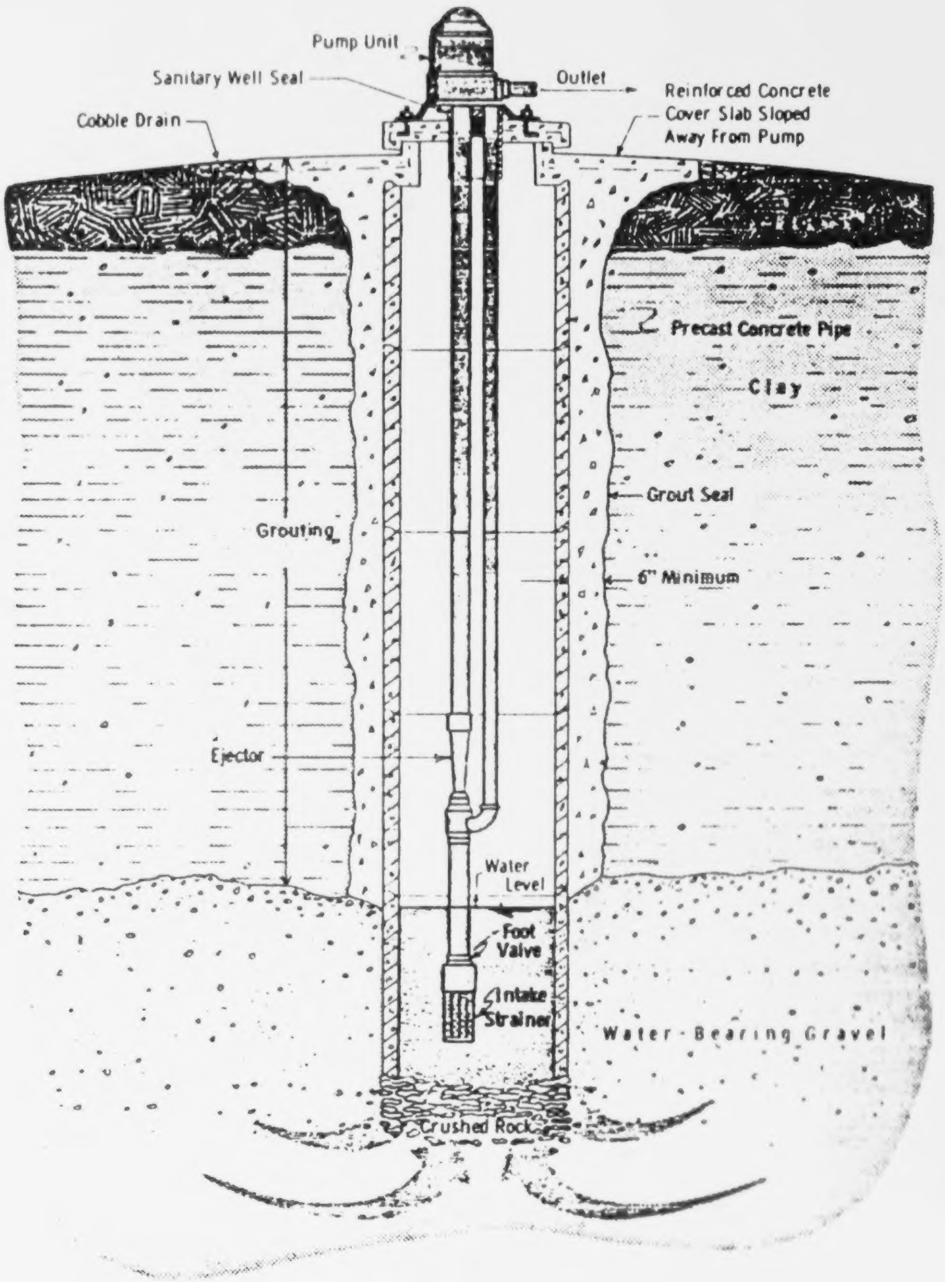
[42] *Alluvial (uh-LOU-vee-ul). Relating to mud and/or sand deposited by flowing water. Alluvial deposits may occur after a heavy rain storm.*

[43] *Permeability (PURR-me-uh-BILL-uh-tee). The property of a material or soil that permits considerable movement of water through it when it is saturated.*

[44] *Slurry (SLUR-e). A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).*

[45] *Annular Space (AN-you-ler). A ring-shaped space located between two circular objects, such as two pipes.*


Pump Unit
Sanitary Well Seal
Outlet
Reinforced Concrete Cover Slab Sloped Away From Pump
Cobble Drain
Precast Concrete Pipe
Clay
Grout Seal
Grouting
6" Minimum
Ejector
Water Level
Foot Valve
Intake Strainer
Water-Bearing Gravel
Crushed Rock

NOTES:

1. Pump screen is placed below point of maximum drawdown.
2. The grouting should be at least six inches thick, form a seal, and placed from the surface cover slab down to the water-bearing gravel.

Fig. 3.41 Dug well with two-pipe jet pump installation

(Source: *MANUAL OF INDIVIDUAL WATER SUPPLY SYSTEMS*, U. S. Environmental Protection Agency, Office of Water Programs, Washington, D.C.)

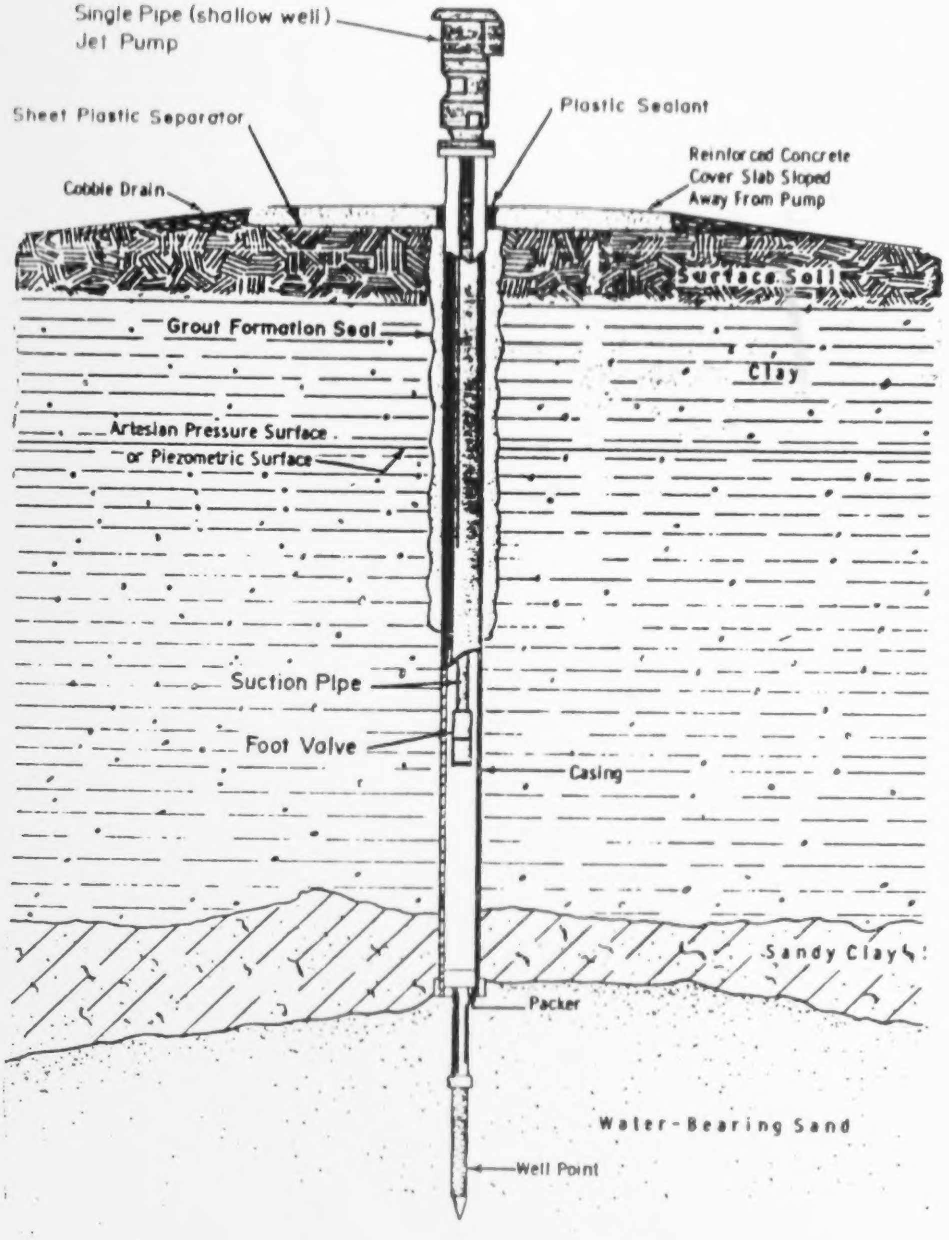
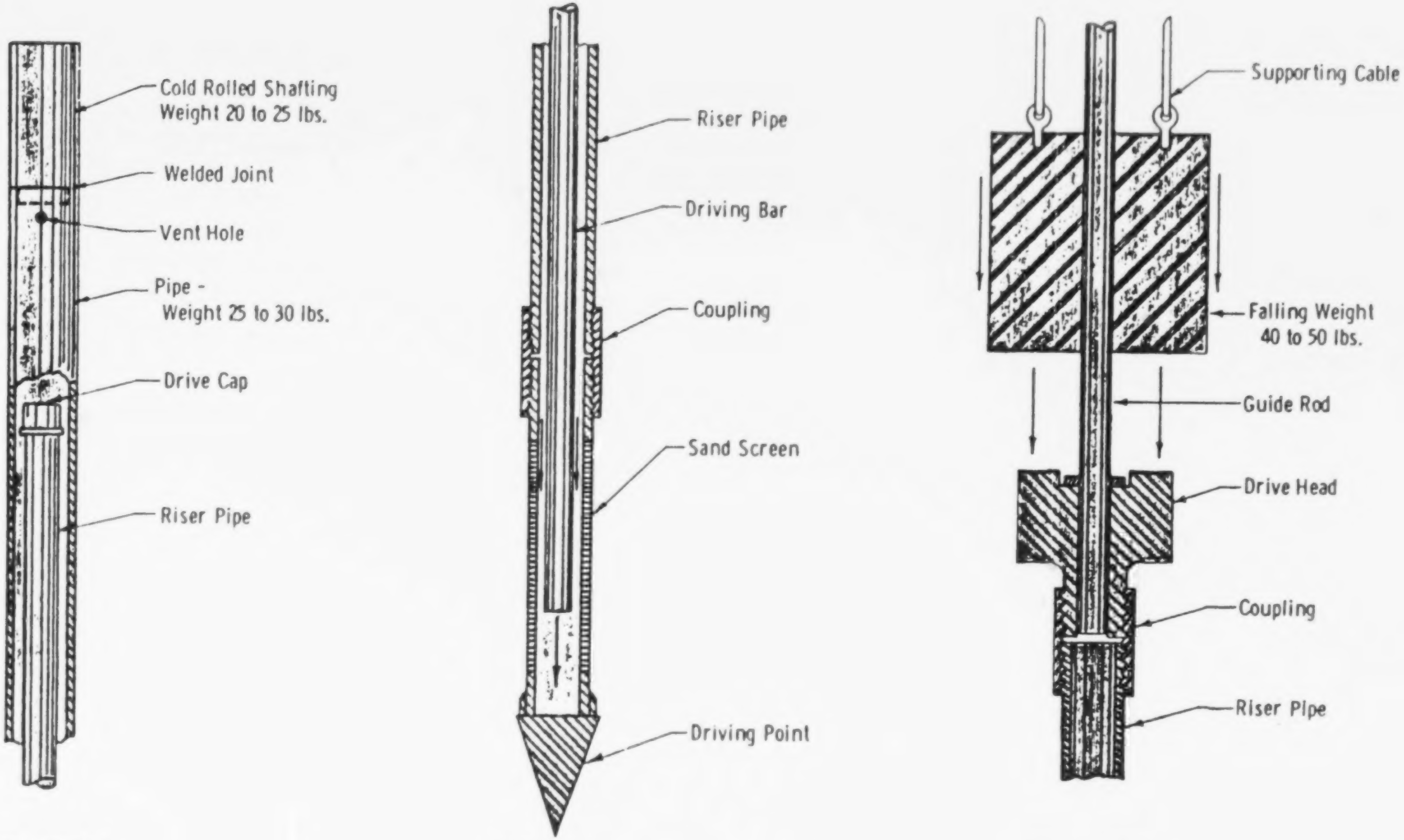

Single Pipe (shallow well) Jet Pump
Sheet Plastic Separator
Plastic Sealant
Reinforced Concrete Cover Slab Sloped Away From Pump
Cobble Drain
Surface Soil
Grout Formation Seal
Clay
Artesian Pressure Surface or Piezometric Surface
Suction Pipe
Foot Valve
Casing
Sandy Clay
Packer
Water-Bearing Sand
Well Point

Fig. 3.42 Hand-bored well with driven well point and "Shallow Well" pump

(Source: *MANUAL OF INDIVIDUAL WATER SUPPLY SYSTEMS*, U.S. Environmental Protection Agency, Office of Water Programs, Washington, D.C.)


Cold Rolled Shafting
Weight 20 to 25 lbs.
Welded Joint
Vent Hole
Pipe -
Weight 25 to 30 lbs.
Drive Cap
Riser Pipe
Riser Pipe
Driving Bar
Coupling
Sand Screen
Driving Point
Supporting Cable
Falling Weight
40 to 50 lbs.
Guide Rod
Drive Head
Coupling
Riser Pipe

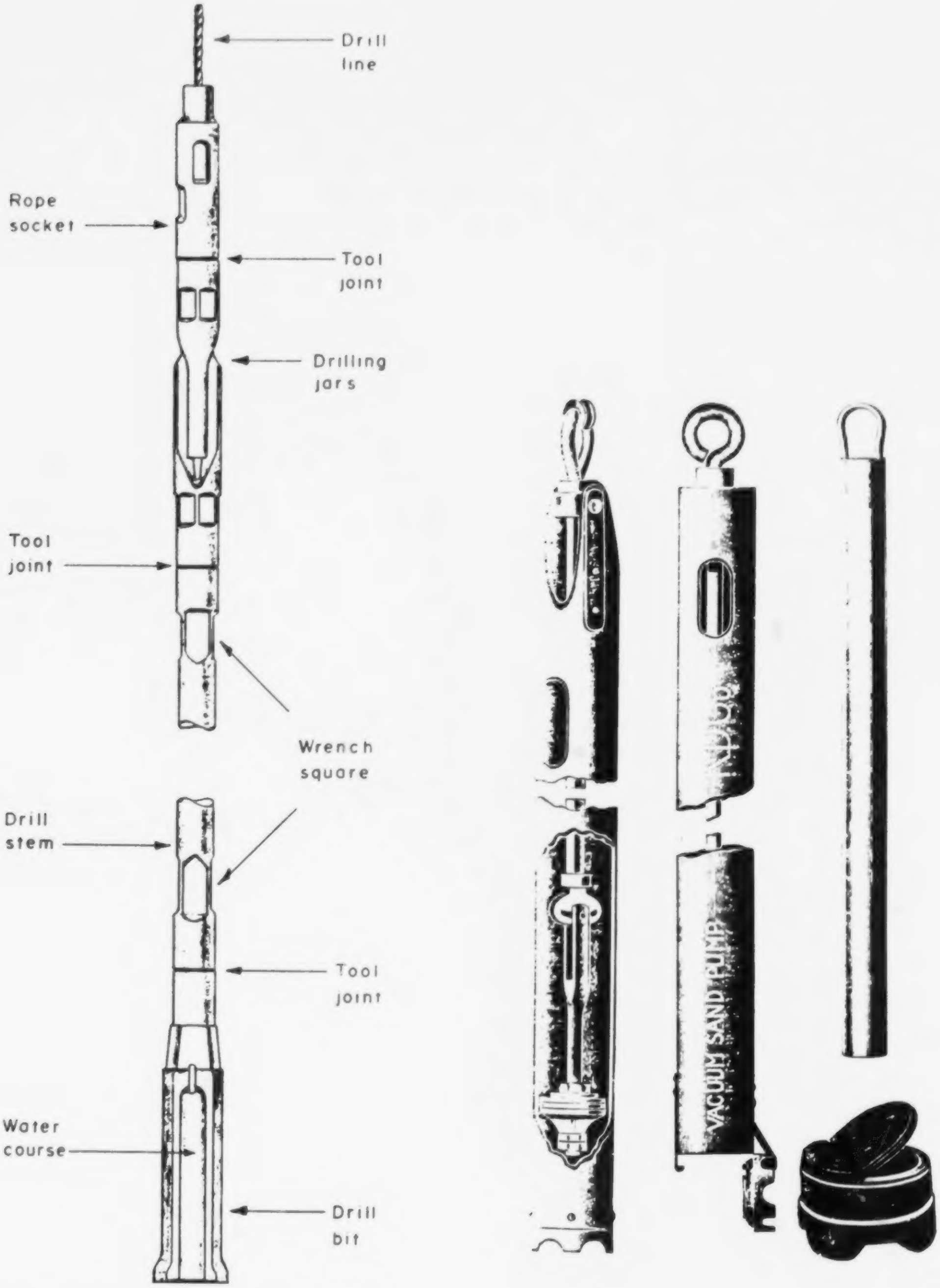
Shafting Weight

Driving Point

Falling Weight

Fig. 3.43 Typical well point for driven wells

(Source: *MANUAL OF INDIVIDUAL WATER SUPPLY SYSTEMS*, U.S. Environmental Protection Agency, Office of Water Programs, Washington, D.C.)


Drill line
Rope socket
Tool joint
Drilling jars
Tool joint
Wrench square
Drill stem
Tool joint
Water course
Drill bit
VACUUM SAND PUMP

Four components of the string of drill tools for cable-tool percussion drilling.

Sand pumps and regular bailer, with details of flat-valve bottoms.

Fig. 3.44 Percussion (Cable-Tool Method)

(Source: *GROUND WATER AND WELLS*,
permission of Johnson Division, UOP, Inc., St. Paul, Minn. 55164)

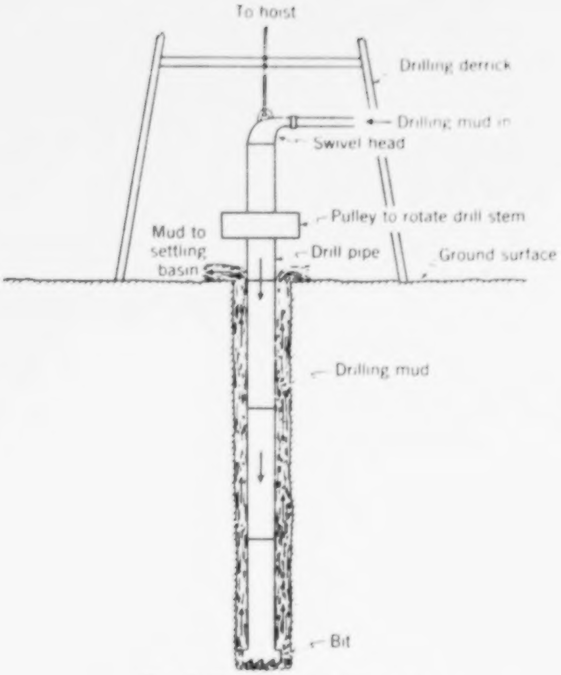


Fig. 3.45 Rotary drilling rig

(Reprinted from *WATER RESOURCES ENGINEERING*, Third Edition, by R. K. Linsley and J. B. Franzini, by permission. Copyright 1979, McGraw-Hill Book Company, New York, New York)

of mud and cuttings is discharged to a settling pit where the cuttings drop to the bottom and mud is recirculated to the drill pipe.

Two types of bits are used in direct rotary drilling (Figure 3.46). A roller or rock type is used to cut the borehole in hard *CONSOLIDATED FORMATIONS*.[46] This type of bit uses a crushing and chipping action between rotating gears to produce fine cuttings that can be carried in suspension by the drilling fluid. The other type of bit, used in sand and clay formations, is the drag type, which has blades arranged in a fishtail or three-way design to cut the borehole.

3.1332 Reverse Circulation Rotary Drilling Method

The reverse circulation rotary drilling method is normally used in drilling large diameter wells in consolidated formations. As the drill bit rotates, a suction pump is used to pull the cuttings through the hollow drill stem to the surface. Water from a supply pit near the rig circulates through a trench and back to the open hole. This water raises the water level in the drill hole to pit level so that *HYDROSTATIC PRESSURE*[47] is applied against the wall of the open hole to prevent caving. Figure 3.47 shows how the direction of circulation is reverse to that employed in the direct rotary drilling method.

3.1333 Air Rotary Drilling Method

Rotary drilling equipment using compressed air as the drilling fluid, rather than drilling mud, is fairly popular. Air is circulated through the center of the drill pipe, out through ports in the drill bit, and upward in the annular space around the drill pipe. The air rotary method requires that air be supplied at pressures from 100 to 250 pounds per square inch (690 to 1725 kPa or 7 to 17 kg/sq cm). To remove the cuttings, ascending air velocities of at lest 3,000 feet per minute (900 m/min) are necessary. *CAUTION.* Never use compressed air to dust off clothing or any part of your body because air can enter the tissues of your body and/or bloodstream and cause serious injury.

Penetration rates of 20 to 30 feet per hour (6 to 9 m/hr) in hard rock are common with air rotary drilling. However, drilling with air as the circulating fluid can be done only in consolidated materials. Air rotary drilling rigs are usually equipped with a conventional mud pump in addition to a high-capacity air compressor. Drilling mud can be used, therefore, in drilling through caving materials above bedrock. Casings may have to be installed through the overburden (looser materials) before continuing with the air rotary method.

3.134 Shallow Collector Wells — Ranney Type

The water collector is a dug well from 12 to 16 feet (3.5 to 5 m) in diameter that has been sunk as a *CAISSON*[48] near the bank of a river or lake. Screen pipes are driven radially and approximately horizontally from this well into the sand and gravel deposits underlying the river (Figure 3.48). The length of these horizontal screens varies from 100 to 300 feet (30 to 90 m). With proper design features, this can be constructed in the flood plain area of certain rivers. Such wells have large capacities, some up to ten million gallons per day (37,850 cu m/day).

3.14 WELL STRUCTURE AND COMPONENTS

3.140 Rules and Regulations Regarding Well Construction

The size, shape and structure of a well can vary significantly from one region to another. State or local ordinances may establish the criteria that must be followed when constructing a well. In some cases, local customs or unusual subsurface formations will dictate the construction method, while in other areas drilling methods may be left entirely up to the well driller.

In this section we will discuss the component parts and construction materials used in typical cable-tool, gravel-envelope, and hard-rock wells. Figure 3.49 shows typical cross-sectional views of the three different types of wells mentioned above. This section will discuss the portion of the well located below the ground surface. In Section 3.1, the "Surface Features of a Well" were discussed.

3.141 Subsurface Features of a Well

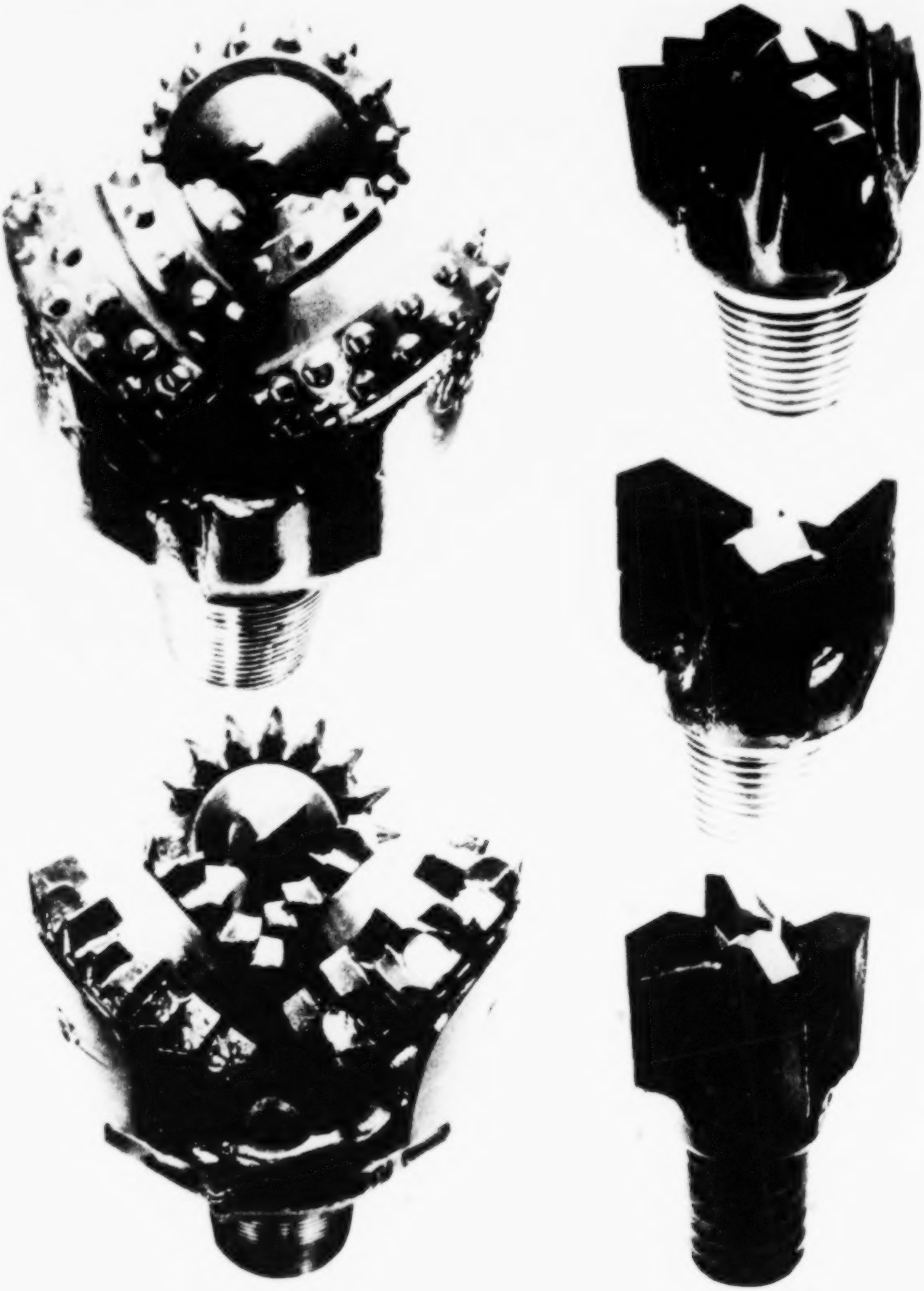
The important *SUBSURFACE* component parts of a typical well include the conductor casing, well casing, well screen or perforated intake section, sanitary grout seal, and the gravel pack or filtering media.

---

[46] *Consolidated Formation. A geologic material whose particles are stratified (layered), cemented or firmly packed together (hard rock); usually occurring at a depth below the ground surface.*

[47] *Hydrostatic Pressure (Hi-dro-STAT-ick). (1) The pressure at a specific elevation exerted by a body of water at rest, or (2) in the case of groundwater, the pressure at a specific elevation due to the weight of water at higher levels in the same zone of saturation.*

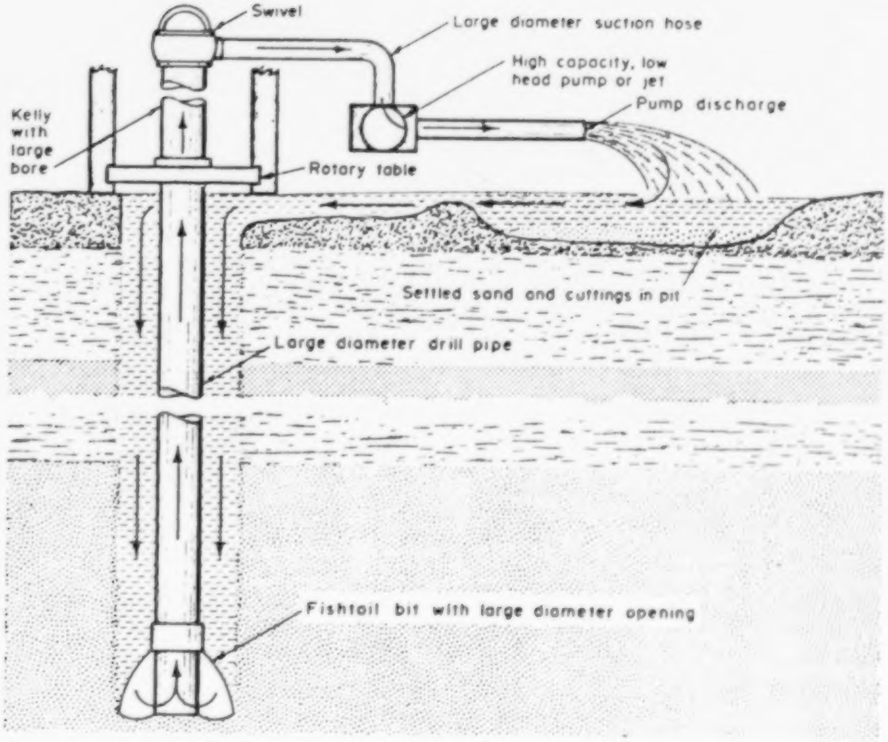
[48] *Caisson (KAY-sawn). A structure or chamber which is usually sunk or lowered by digging from the inside. Used to gain access to the bottom of a stream or other body of water.*



Roller or rock type

Drag or fish tail type

Fig. 3.46 Rotary drilling bits
(Permission of Varel Manufacturing Company)


Swivel
Large diameter suction hose
High capacity, low head pump or jet
Pump discharge
Kelly with large bore
Rotary table
Settled sand and cuttings in pit
Large diameter drill pipe
Fishtail bit with large diameter opening

NOTE: Kelly. The square section of a rod which causes the rotation of a drill bit. Torque from a drive table is applied to the square rod to cause the rotary motion. The drive table is chain or gear driven by an engine.

Fig. 3.47 Basic principles of reverse circulation rotary drilling are shown by this schematic diagram. Cuttings are lifted by upflow inside drill pipe.

(Source: *GROUND WATER AND WELLS*, permission of Johnson Division, UOP, Inc., St. Paul, Minn. 55164)

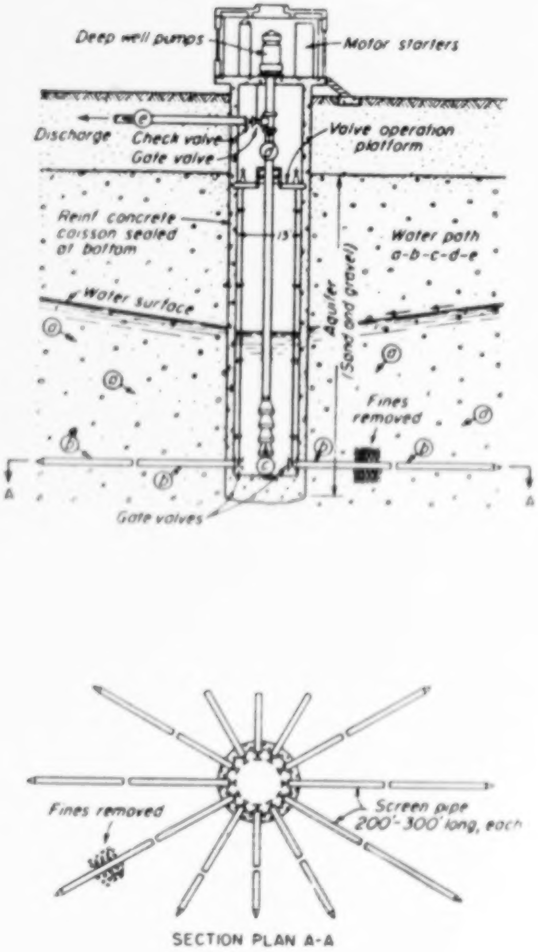
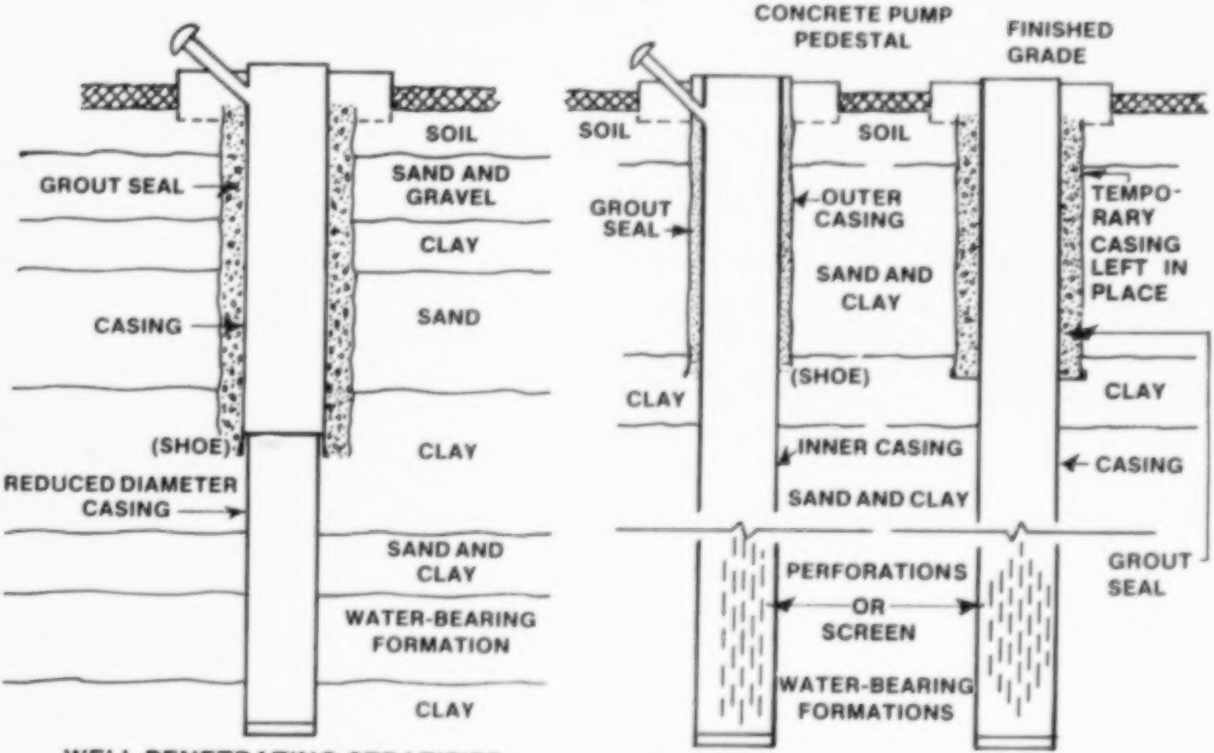

Deep well pumps
Motor starters
Discharge
Check valve
Gate valve
Valve operation platform
Reinf concrete caisson sealed at bottom
13'
Water path a-b-c-d-e
Water surface
Aquifer (Sand and gravel)
Fines removed
a
b
c
d
e
A
A
Gate valves
Fines removed
Screen pipe 200'-300' long, each
SECTION PLAN A-A

Fig. 3.48 Typical shallow collector-type well (often referred to as a Ranney collector)

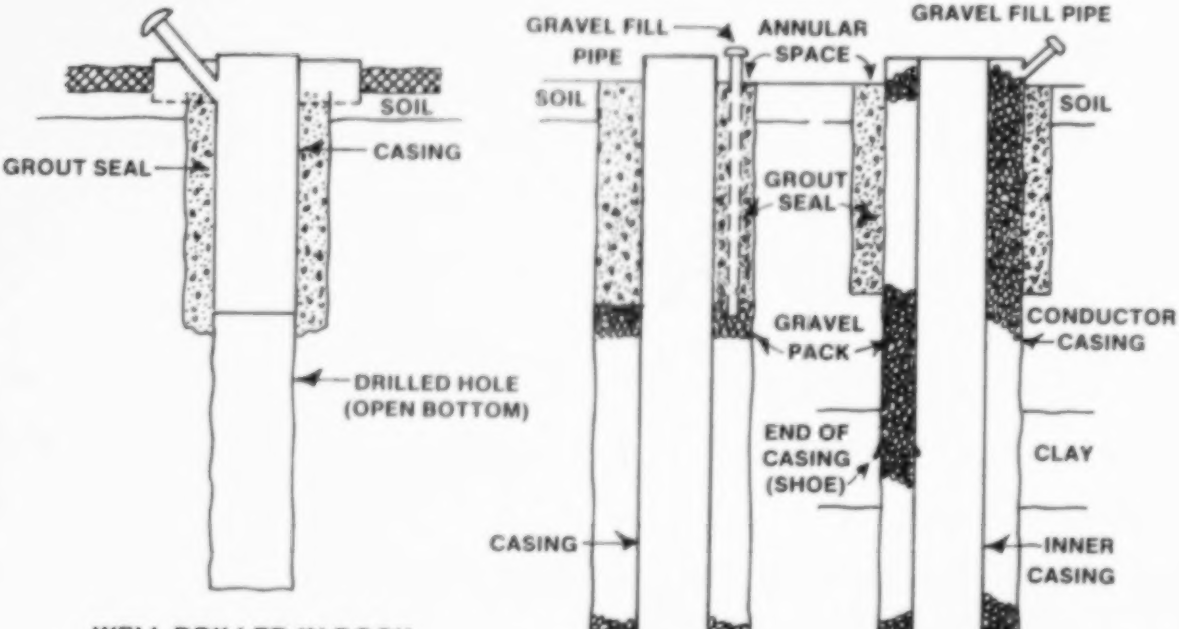
(From R. Nebolsine, J. New Engl. Water Works Assoc., Vol. 57, p. 191, 1943)


SOIL
SAND AND GRAVEL
GROUT SEAL
CLAY
CASING
SAND
CLAY
(SHOE)
CLAY
REDUCED DIAMETER CASING
SAND AND CLAY
WATER-BEARING FORMATION
CLAY
CONCRETE PUMP PEDESTAL
FINISHED GRADE
SOIL
SOIL
GROUT SEAL
OUTER CASING
SAND AND CLAY
TEMPORARY CASING LEFT IN PLACE
(SHOE)
CLAY
CLAY
INNER CASING
CASING
SAND AND CLAY
GROUT SEAL
PERFORATIONS OR SCREEN
WATER-BEARING FORMATIONS

WELL PENETRATING STRATIFIED FORMATIONS

A. CABLE-TOOL B. ROTARY

WELLS DRILLED IN UNCONSOLIDATED MATERIAL, CAVING FORMATIONS


SOIL
GROUT SEAL
CASING
DRILLED HOLE (OPEN BOTTOM)
GRAVEL FILL PIPE
ANNULAR SPACE
GRAVEL FILL PIPE
SOIL
SOIL
GROUT SEAL
GRAVEL PACK
CONDUCTOR CASING
END OF CASING (SHOE)
CLAY
CASING
INNER CASING

WELL DRILLED IN ROCK FORMATION

A. WITHOUT CONDUCTOR CASING B. WITH CONDUCTOR CASING

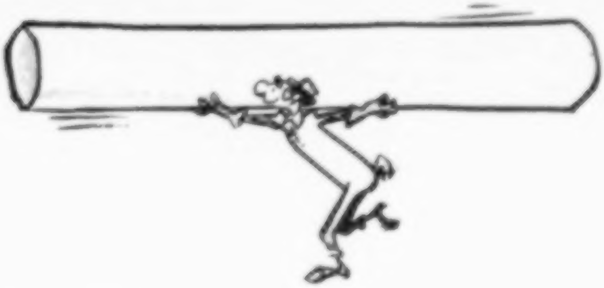
GRAVEL PACKED WELLS

Fig. 3.49 Typical cross-sectional views of different types of wells

We will review each of these parts in detail, but before we do that, let's discuss the importance of the sanitary grout seal. From a sanitary health and water utility viewpoint, the most important part of any well is the portion from ground level down to the point where the sanitary grout seal ends. This upper zone of the well must be effectively sealed to protect the well against contamination or pollution by surface or shallow subsurface waters, and against improper disposal of liquid wastes and wastewater-related hazards. If this section of the well is not properly designed and installed, then the useful life of the well and also the aquifer is in jeopardy.

The component parts of the sanitary seal include the conductor casing, the upper portion of the well casing, and the grouting material itself.

Now let us review each of the *SUBSURFACE* components in more detail, keeping in mind that construction, design and materials can vary significantly from one geographic area to another.



3.142 Conductor Casing

The conductor casing is the outer casing of a well (see Figure 3.49, Gravel Packed Wells, B. with Conductor Casing). The purpose of the conductor casing is to prevent contaminants from surface waters or shallow groundwaters from entering the well.

For community water supply wells, the minimum thickness of the steel conductor casing should be ¼ inch (6 mm) for single casing and 10-gage for double casing. Steel used for conductor casing should be mild low-carbon steel similar to ASTM-A 139 Grade B. The casing should extend 18 inches (450 mm) above the ground surface.

1. Cable-Tool Wells: The conductor casing should be at least 4 inches (100 mm) larger in diameter than the well casing.
2. Gravel-Envelope Wells: The conductor casing should be at least 12-inches (300 mm) larger in diameter than the well casing.
3. Hard-Rock Wells: The conductor casing should be at least 4-inches (100 mm) larger in diameter than the well casing. However, the well casing also functions as the conductor casing in many instances.
4. Depth of Conductor Casing: The conductor casing should extend down and into an impervious stratum where no liquid can flow in or out. As a minimum, the conductor casing should be 50 feet (15 m) in depth. In some cases, the casing might extend down to 150 feet (45 m) or more if the nature of the upper stratum and the degree of hazard require the extra protection. State or county health authorities often establish guidelines for the minimum depth of a conductor casing and sanitary seal.

3.143 Well Casing

The functions of the well casing are: (1) to maintain the well hole by preventing its walls from collapsing, (2) to provide a way to get the water to the pumping unit, (3) to form a chamber or housing for the well pump, and (4) to protect the quality of water pumped.

The diameter of the well casing is generally determined by the amount of water that the water utility desires to pump from the well and by the safe yield of the well. Table 3.5 shows the recommended casing diameters for various ranges of well yields or pumping rates.

A careful review of this table shows that, in most cases, the casing should be at least 4 inches (100 mm) larger in

TABLE 3.5 RECOMMENDED WELL DIAMETERS

Anticipated Well Yield, GPM	Nominal Size of Pump Bowls,[a] inches	Optimum Size of Well Casing, inches	Smallest Size of Well Casing, inches
Less than 100	4	6 ID[b]	5 ID
75 to 175	5	8 ID	6 ID
150 to 400	6	10 ID	8 ID
350 to 650	8	12 ID	10 ID
600 to 900	10	14 ID	12 ID
850 to 1300	12	16 OD[c]	14 OD
1200 to 1800	14	20 OD	16 OD
1600 to 3000	16	24 OD	20 OD

[a] Pump Bowls. The submerged pumping unit in a well, including the shaft, impellers and housing.
[b] ID. Inside Diameter
[c] OD. Outside Diameter

diameter than the *PUMP BOWLS.*[49] The two-inch (50 mm) clearance on all sides allows the pump bowl and column assembly to move freely in the well during installation and removal. This much clearance is necessary in case a well is slightly crooked or out of plumb. In some cases, however, the size of the well casing may be determined by the drilling capability of drilling rigs in the area and availability of well casing.

3.144 Intake Section of a Well

3.1440 Purpose of Intake Section

Another important subsurface feature of a well is the intake section located at or near the bottom of the well and attached to the end of the well casing. The intake section of the well permits the free flow of water from water-bearing formations into the well itself, while at the same time it supports the water-bearing formations and prevents the drill hole from collapsing. In most cases, the intake section also performs the important function of preventing sand from entering the well.

The intake section may take the form of (1) a well screen, (2) mill cut slots, (3) formed louvers, (4) torch-cut/chisel-cut slots, and (5) slots made by a mechanical perforator after the well has been completed. These five types of intake sections are described in the following paragraphs.

3.1441 Well Screens

The three basic types of well screens are continuous slot, bar, and wire-wound. They are generally constructed of stainless steel, monel metal, special nickel alloys, silicon red brass, red brass, special alloy steel, and plastic.

The length and diameter of the screen section is typically based on the expected yield of the well. Frequently, screen sections are installed at more than one location in the well to fully utilize all of the desirable water-producing formations. The size of the screen openings may vary from formation to formation, depending upon the various aquifer materials that might clog them. The size of the screen openings is determined by the *EFFECTIVE SIZE*[50] and *UNIFORMITY COEFFICIENT*[51] of the sands in the water-bearing strata.

The slots or openings in the screen should have sufficient open area so that the water flowing from the water-bearing formations through the screen openings does not exceed a recommended velocity of 0.1 feet per second (0.03 m/sec). This recommended velocity may vary according to local conditions, health departments and manufacturers.

Figure 3.50 illustrates a few typical sections of well screens.

3.1442 Mill-Cut Slots

Mill-cut slots intake sections are typically made at the well casing manufacturer's plant from the same type and diameter of well casing that was selected for the well. The openings are machine milled (cut) into the wall of the casing pipe parallel to the axis of the casing and uniformly spaced around the casing pipe at approximately 2-inch (50 mm) intervals. The slot openings are typically 1/16 to 1/8 inches (1.5 to 3 mm) wide by 2 to 6 inches (50 to 300 mm) long. The slot width is determined by the size of the aquifer material it must keep out. The rows are sometimes staggered and placed several inches apart. Figure 3.51 illustrates several different types of mill slotted intake sections.

Mill-cut slots are still used but may be on the decline due to the increased popularity of the louvered casing.

ALL OUR SLOTS GUARANTEED MILL CUT

3.1443 Formed Louvers

Research and development of the formed louver has made this type of intake section a very popular product.

The openings or louvers in the well casing are machine made, horizontal to the axis of the casing, with the openings facing downward. The louvers are shaped to create an upward flow as water enters the well. The louvers are spaced close together in vertical rows as shown in Figure 3.52. As with other types of intake sections, the size of the openings is determined by the aquifer material.

Louvered casing is available in a variety of materials ranging from stainless steel to mild steel. The diameter of the louvered casing is usually the same diameter as the well casing and is available in 10, 15, and 20-foot (3, 4.5 and 6 m) lengths.

Use of properly sized openings and properly selected and sized gravel will produce optimum results. The louvered sections are usually installed directly opposite the desired water-bearing strata. However, in situations where the water-bearing strata are separated by thin layers of consolidated material, a continuous length of louvered casing is often used rather than inserting short lengths of blank (non-louvered) well casing. This practice allows for better placing and setting of the gravel pack, quicker well cleanup and shorter development time, and tends to draw the maximum water yield from the selected water-bearing formations.

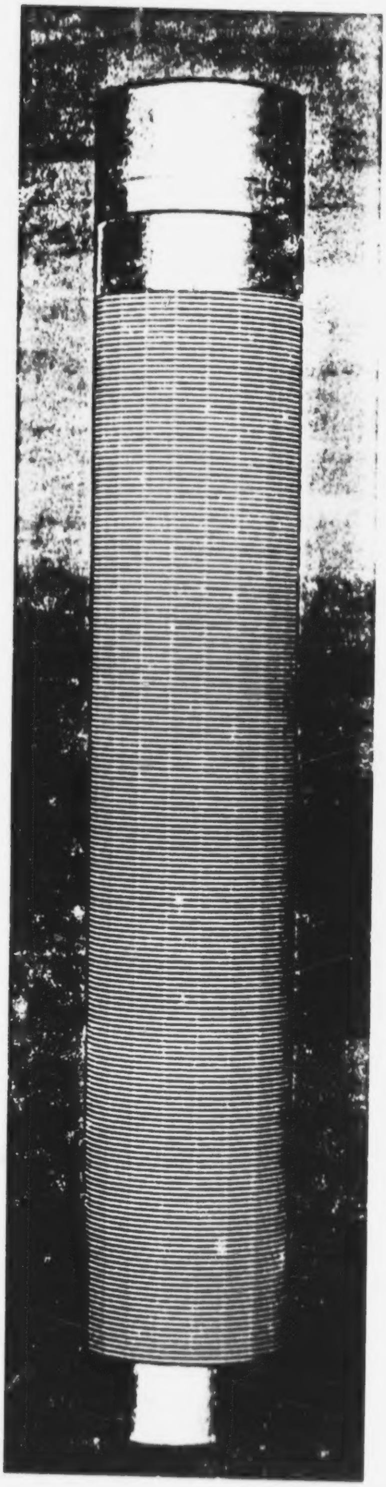
---

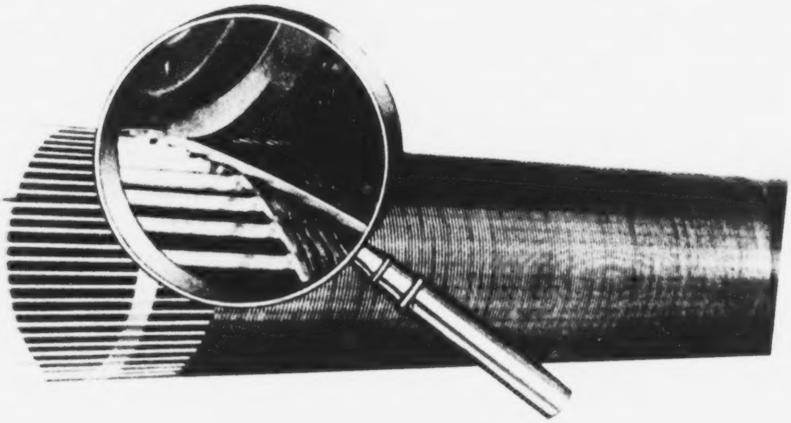
[49] *Pump Bowls. The submerged pumping unit in a well, including the shaft, impellers and housing.*

[50] *Effective Size. The diameter of the particles in a granular sample (sand) for which 10 percent of the grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.*

[51] *Uniformity Coefficient. The ratio of (1) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through.*

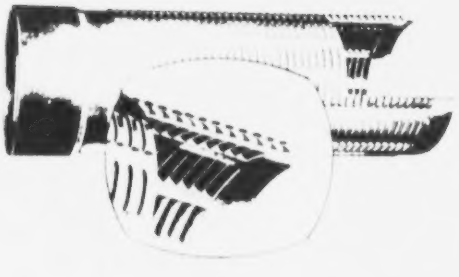
$$\text{Uniformity Coefficient} = \frac{\text{Particle Diameter, 60\%}}{\text{Particle Diameter, 10\%}}$$





Fabricating the Johnson Well Screen — an all-welded, continuous-slot well screen for water wells and oil wells. Screen may be made of any metal or alloy that can be resistance welded.

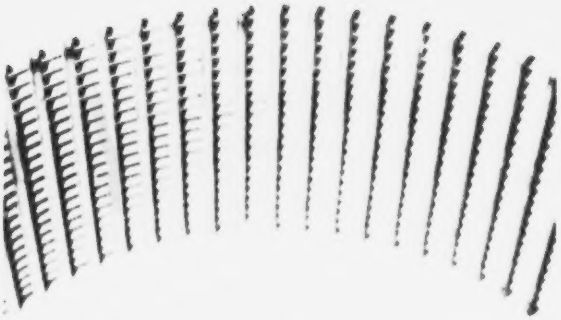
(Source: *GROUND WATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, Minn. 55164)

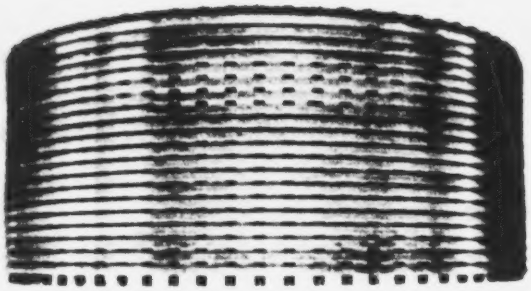


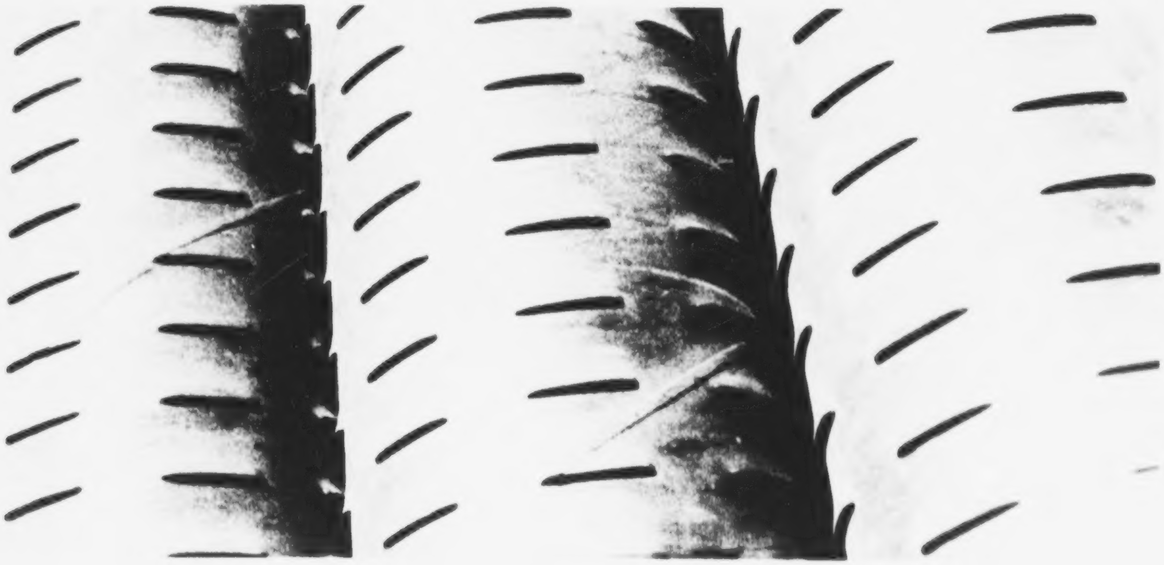
Sections through well screens.

(Permission of Layne and Bowler, Inc., Memphis, Tennessee)

Fig. 3.50 Typical sections of well screens



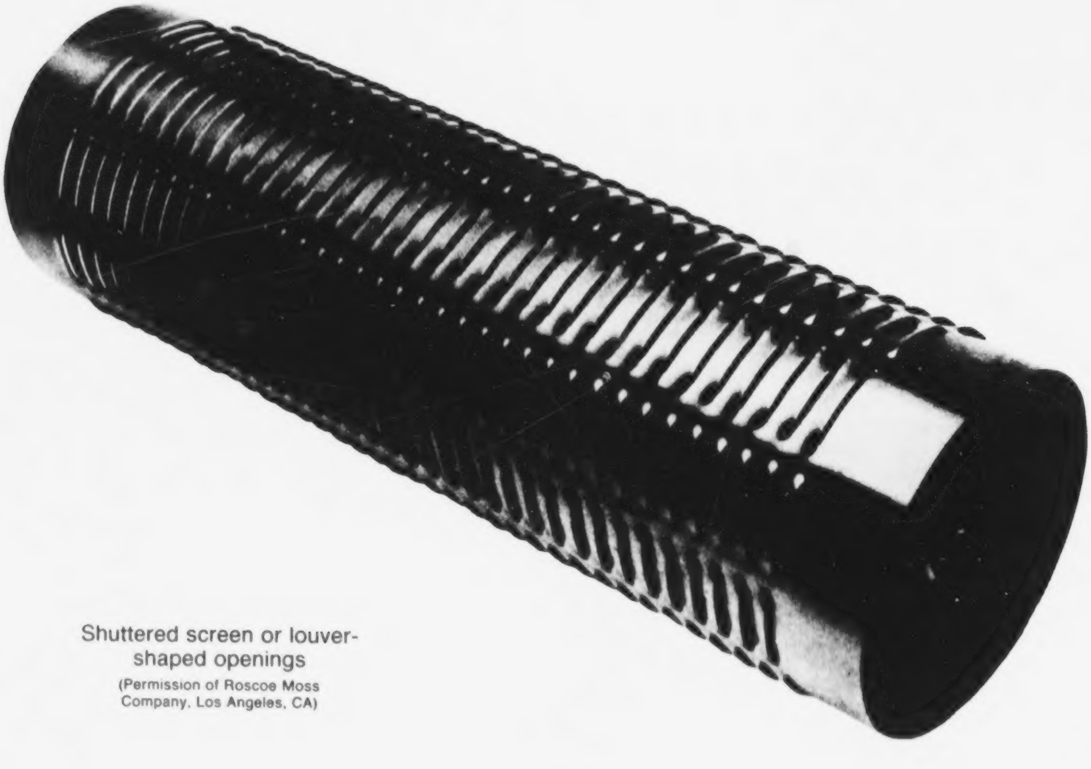




Perforated casing.

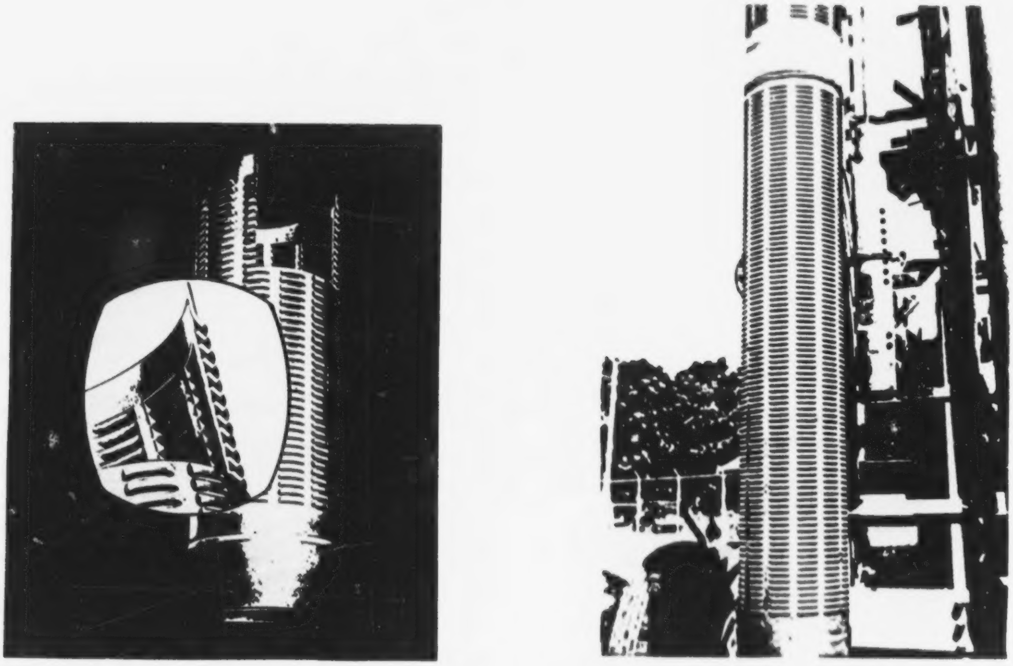
Fig. 3.51 Different types of intake sections

(Source: *WATER WELLS AND PUMPS: THEIR DESIGN, CONSTRUCTION OPERATION AND MAINTENANCE*, Division of Agricultural Sciences University of California, Davis)



Shuttered screen or louver-shaped openings

(Permission of Roscoe Moss Company, Los Angeles, CA)



Well casing louvers

(Permission of Layne & Bowler, Inc., Memphis, Tennessee)

Fig. 3.52 Well casing openings or louvers

3.1444 Torch-Cut Slots

Torch-cut and chisel-cut slots should be avoided. Well drillers find it next to impossible to control the size of the openings in the well casing and to maintain the correct open area per foot of casing. Without this type of control, the well is likely to produce sand in excessive quantities. See Figure 3.53 for examples of unacceptable torch-cut and chisel-cut slots.

3.1445 Hydraulic or Mechanical Slots

Cable-tool wells are usually slotted after the well has been drilled. The openings are made opposite the water-bearing formations by means of a casing perforator tool lowered into the well and activated from the drill rig.

This method of producing openings or slots in the well casing has serious limitations because the openings cannot be closely spaced, the percentage of open area is low, the opening size and shape can vary, and the correct size openings to control fine or medium sand are almost impossible to produce.

3.145 Annular Grout Seal (Figure 3.54)

The purpose of the annular grout seal is to seal out water of any unsatisfactory chemical or bacterial quality, to protect the well casing or conductor casing pipe against exterior corrosion, and to stabilize soil formations which are of a caving nature.

Grouting or cementing is simply filling with cement or other suitable material (1) the annular space between the well casing and the conductor casing; or (2) the space between the conductor casing and the bore hole; or (3) the space between the well casing and the bore hole.

However, an *OPTIONAL* sanitary sealing method (Figure 3.61, page 155) also has been used for gravel-envelope wells. The typical outside conductor casing is eliminated and the annular space between the well casing and the oversize bore hole is cemented.

In order to provide access for further graveling, a 4-inch (100 mm) standard steel pipe is placed in the annular space extending from above ground down to the area where the gravel envelope is needed. In order to insure a good seal around the 4-inch (100 mm) graveling pipe, the thickness of the grout is usually increased to 6 or 8 inches (150 to 200 mm).

This new optional method requires an extra thick grout seal and a 4-inch (100 mm) pipe for adding gravel, but does eliminate the expensive outside conductor casing and bore hole. On a typical 14-inch (350 mm) diameter well, the conductor casing is 30 inches (750 mm) in diameter and the bore hole for the conductor casing is 36 inches (900 mm) across.

Hard-Rock Wells: In consolidated formations, the general practice is to extend the well casing down and into the water-bearing rock formation for a minimum distance of 5 feet (1.5 m). Then the annular space between the well casing and the bore hole is cemented. This grout seal should also be a minimum of 2-inches (50 mm) thick. The balance of the bore hole through the water-bearing rock formations is left uncased. Water enters the uncased area of the well by way of the fissures and voids in the rock formations.

3.146 Sealing Material

The material used for sealing grout should consist of neat cement grout, sand-cement grout, or bentonite clay. Cement used for sealing mixtures must meet the requirements of ASTM C-150 "Standard Specifications for Portland Cement" Type I (common construction cement) or Type III (high early strength).

3.147 Placement of Sealing Material

Before placing the sealing material in position, all loose cuttings, drilling mud, or other obstructions should be removed from the annular space by flushing with water.

There are three basic methods for placing the sealing material in the annular space when a conductor casing is used. The methods are grout pipe outside casing, grout pipe inside casing, and the Halliburton Method.

No drilling or work in the well should be permitted until the cement grouting materials have developed sufficient strength to prevent damage to the seal.

3.148 Gravel Pack

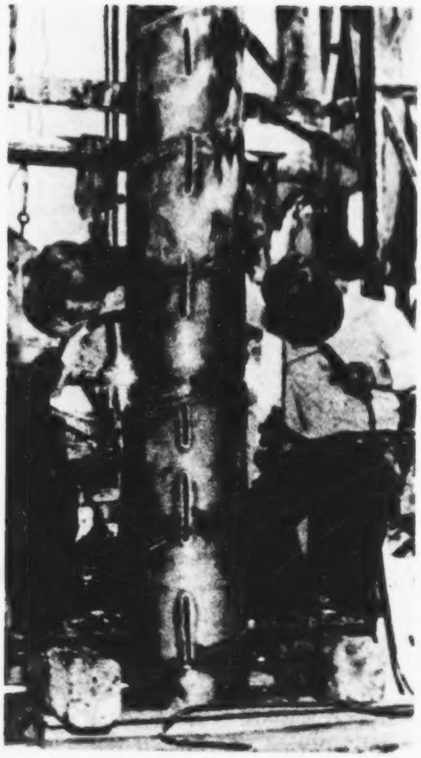
The purpose of the gravel pack is to control the entrance of sand into the well. The size (or combination of sizes) of gravel selected for the gravel pack is determined by an analysis of the grain size of the water-bearing aquifer materials encountered during the drilling operation. The goal is to select a gravel pack which, while still maintaining sand control, will allow the largest possible screen or slot opening and thus increase the flow into the well.

WHENEVER PLACING GRAVEL IN A WELL, THE GRAVEL MUST BE DISINFECTED WITH A STRONG CHLORINE SOLUTION (50 mg/L) BEFORE INSTALLATION TO AVOID CONTAMINATING THE WELL.

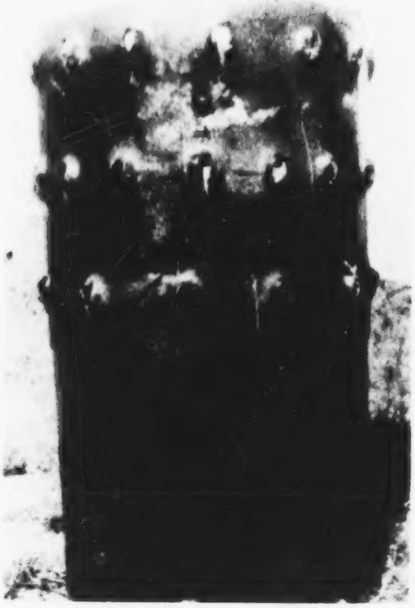
Another type of gravel-envelope construction is the "Layne Underreamed Gravel Wall" method developed by Layne and Bowler, Inc., of Memphis, Tennessee. With this method, the water-bearing formation is underreamed (the hole is made larger under the clay layer, Figure 3.55), after the permanent upper casing is set in place. A screen or louvered section of the proper diameter and length is centered in the larger diameter of the underreamed hole. Selected and graded gravel is placed around the screen or louvered section, resulting in a gravel envelope held in place by a long-lasting intake section. This design allows for a maximum flow of water into the well and is a very efficient groundwater-producing unit.

3.15 DETERMINATION OF WORKING PRESSURE

Hydropneumatic pressure tanks are used to provide a consistent range of suitable pressures in the distribution system despite changing demands and pump cycling. Other



In torch-cut, slotted pipe, percent open area is low and width of slots is too large to permit developing well to sand-free condition.



Casing perforator produces crude, jagged openings of uncontrolled size.

Fig. 3.53 Examples of unacceptable torch-cut and chisel-cut slots

(Source: *GROUND WATER AND WELLS*, permission of Johnson Division, UOP, Inc., St. Paul, Minn.)

reasons for using a hydropneumatic pressure tank system are:

1. Gravity storage may not be practical or available due to the lack of elevation differentials within the service area.
2. By using the best operating pressure differential and control levels in the tank (referred to as "tank efficiency"), the time period between start-stop operation of the pump can be extended considerably, thereby reducing the cycling frequency of the pump. Excessive pump cycling increases the wear on the pump and its parts, plus using additional energy.
3. Hydropneumatic tanks maintain distribution system pressures within predetermined limits by maintaining a cushion of compressed air in the top portion of the tank. In effect, this provides stored energy to force the water out as the pressure in the distribution system drops.
4. The compressed air in the tank greatly reduces the hydraulic shock load on the system when the well pump starts and stops.

The effective (usable) water storage capacity in a horizontal hydropneumatic tank is limited to approximately 25 percent of the total capacity of the tank.

You can select the best operating pressure differential, the control levels in the tank, the pumping differential and the tank efficiency and tank size by studying Figures 3.56 and 3.57 and working through the following examples.

As an example, let's study a typical 5,000-gallon capacity horizontal tank, six feet in diameter by approximately 25 feet in length, with the inlet and outlet connections in the bottom of the tank, and an *OPERATING PRESSURE DIFFERENTIAL*[52] of 20 psi (from 40 to 60 psi). For this example, the most efficient tank operating criteria would require the pump start point or low water level (LWL) to be set at 12 inches (30 cm) above the bottom of the tank; set the pump stop point or high water level (HWL) at 27 inches (67 cm) above the bottom of the tank. If the tank is constructed with an outlet connection that extends up into the tank (generally 6 to 10 inches (15 to 25 cm)) as is a common practice if the well produces sand, then the LWL in the tank must be maintained

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[52] *Operating Pressure Differential. The operating pressure range for a hydropneumatic system. For example, when the pressure drops below 40 psi the pump will come on and stay on until the pressure builds up to 60 psi. When the pressure reaches 60 psi the pump will shut off.*

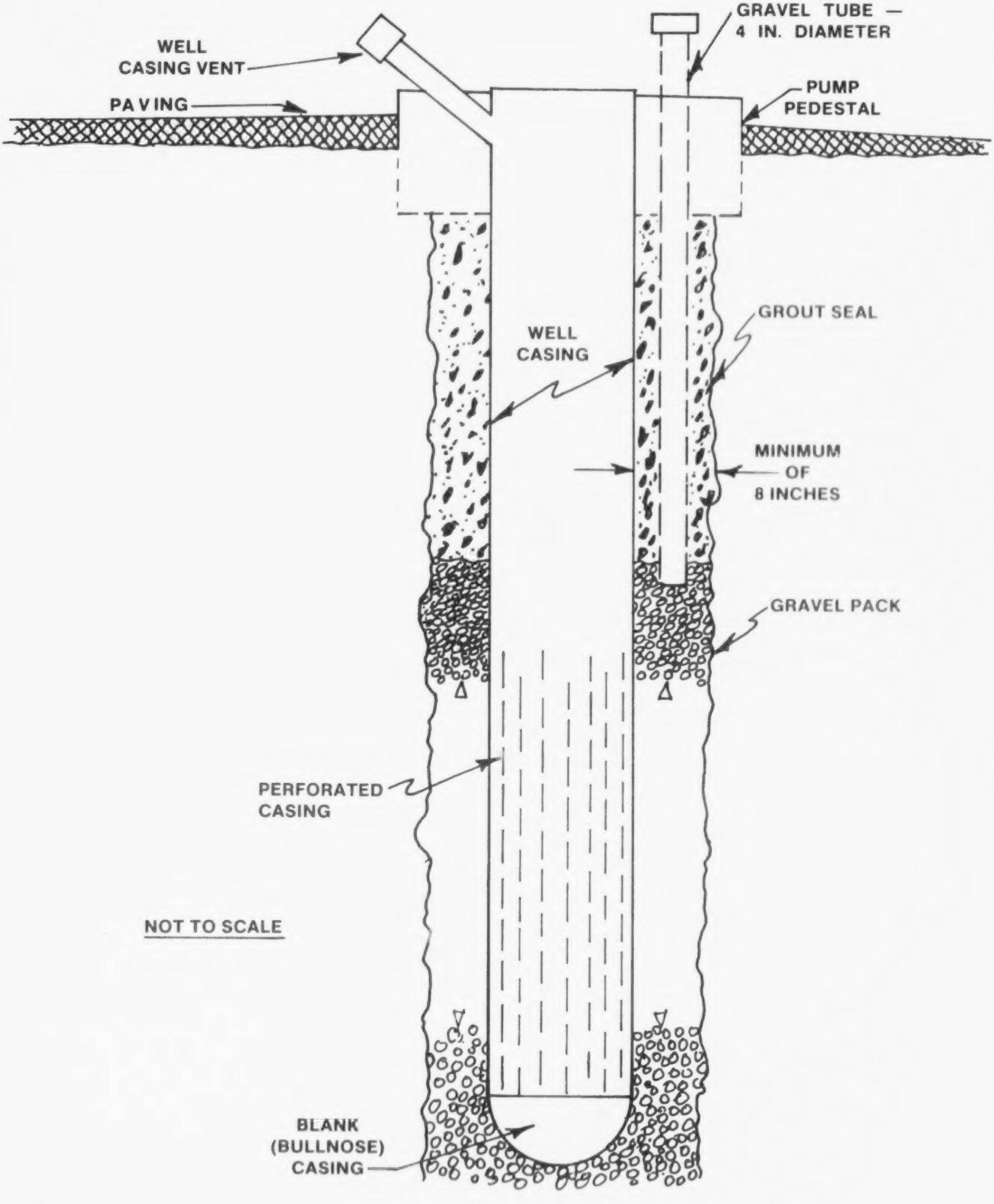
WELL CASING VENT
PAVING
GRAVEL TUBE — 4 IN. DIAMETER
PUMP PEDESTAL
GROUT SEAL
WELL CASING
MINIMUM OF 8 INCHES
GRAVEL PACK
PERFORATED CASING
NOT TO SCALE
BLANK (BULLNOSE) CASING

Fig. 3.54 Sanitary sealing method for gravel-envelope wells

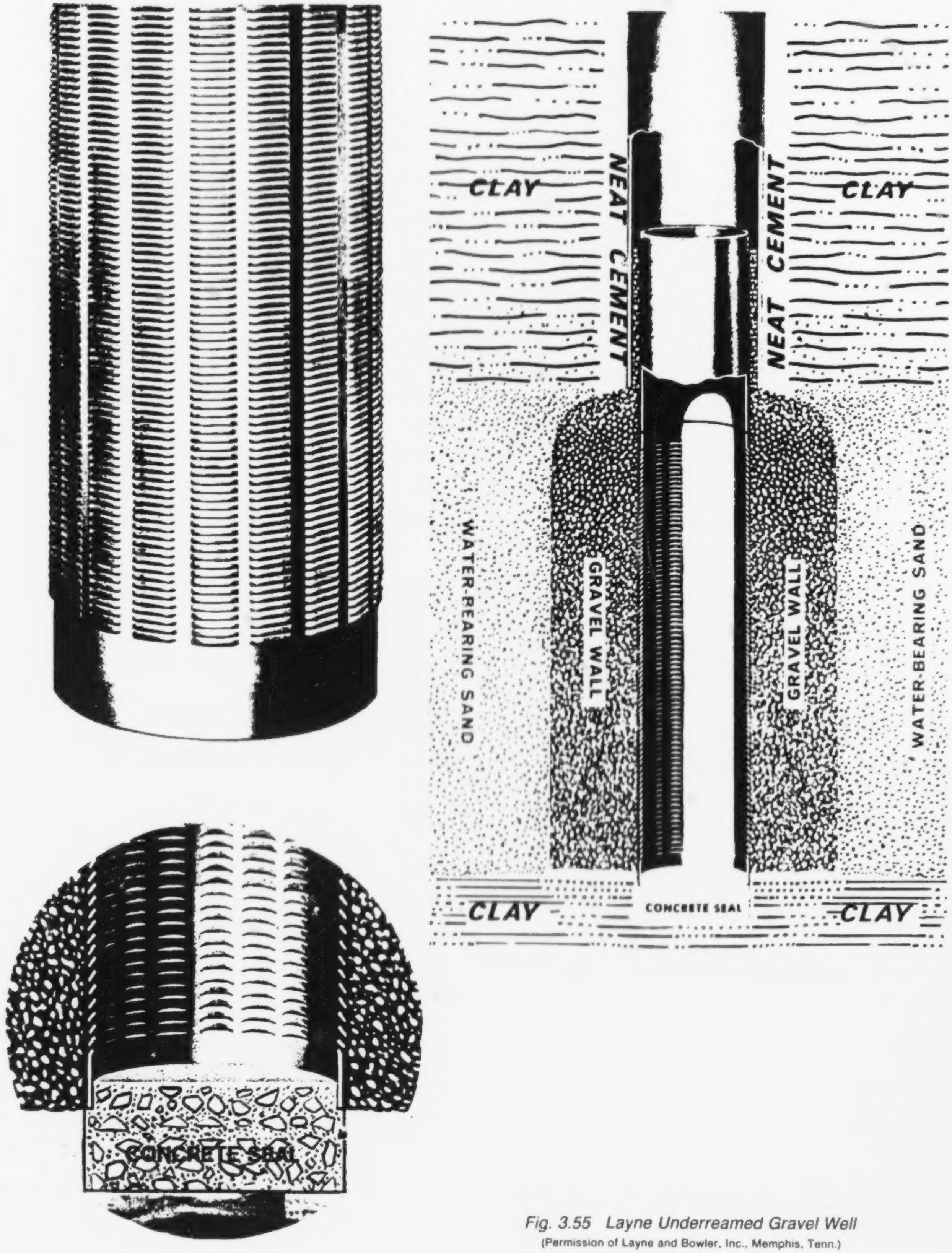
CLAY
NEAT CEMENT
NEAT CEMENT
CLAY
WATER-BEARING SAND
GRAVEL WALL
GRAVEL WALL
WATER-BEARING SAND
CLAY
CONCRETE SEAL
CLAY
CONCRETE SEAL

Fig. 3.55 Layne Underreamed Gravel Well

(Permission of Layne and Bowler, Inc., Memphis, Tenn.)

PRESSURE AND VOLUME DIFFERENTIALS FOR HYDROPNEUMATIC TANKS
(PRESSURE TANK IN PSI)

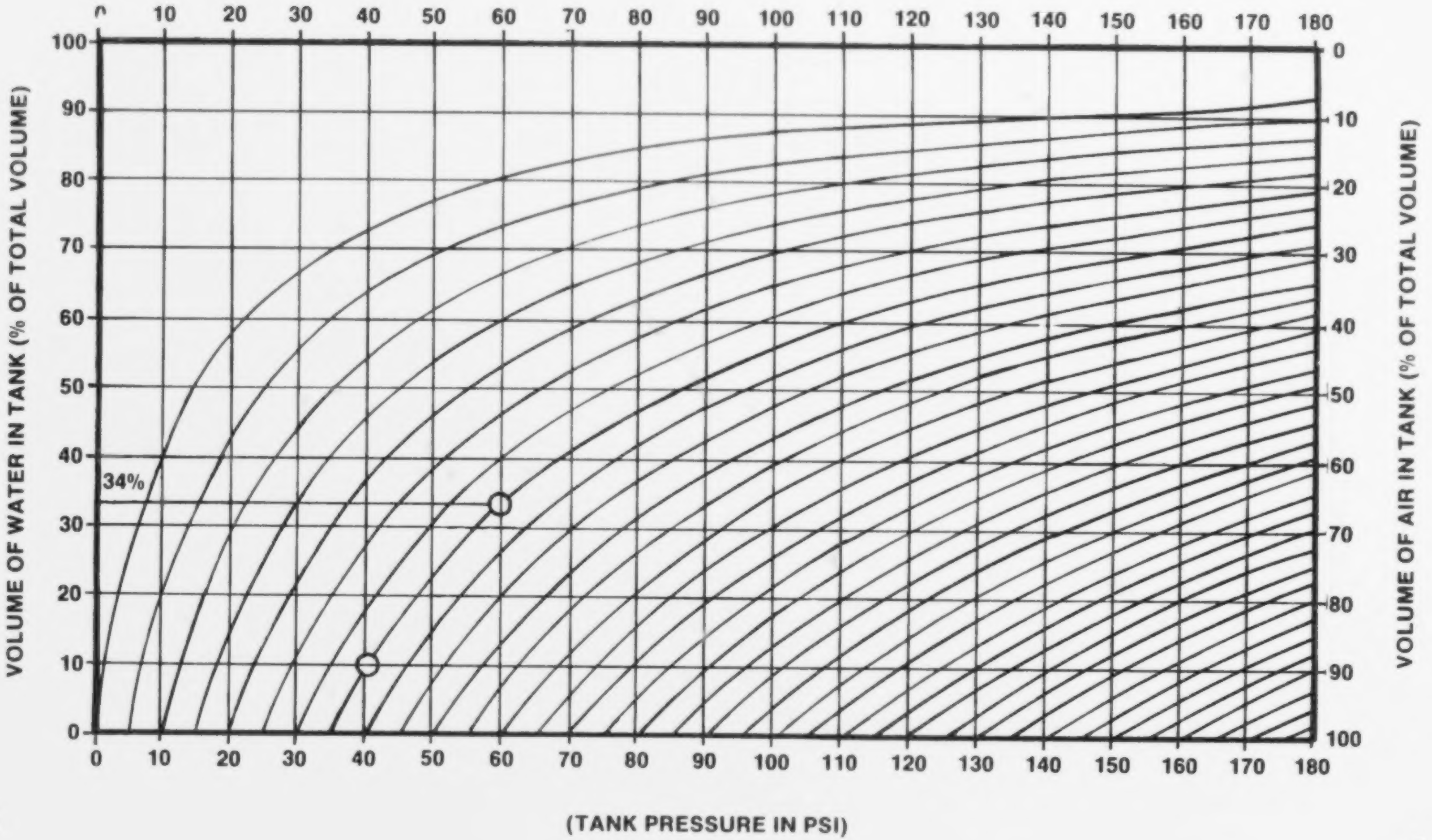

Fig. 3.56 Pressure-volume determination chart

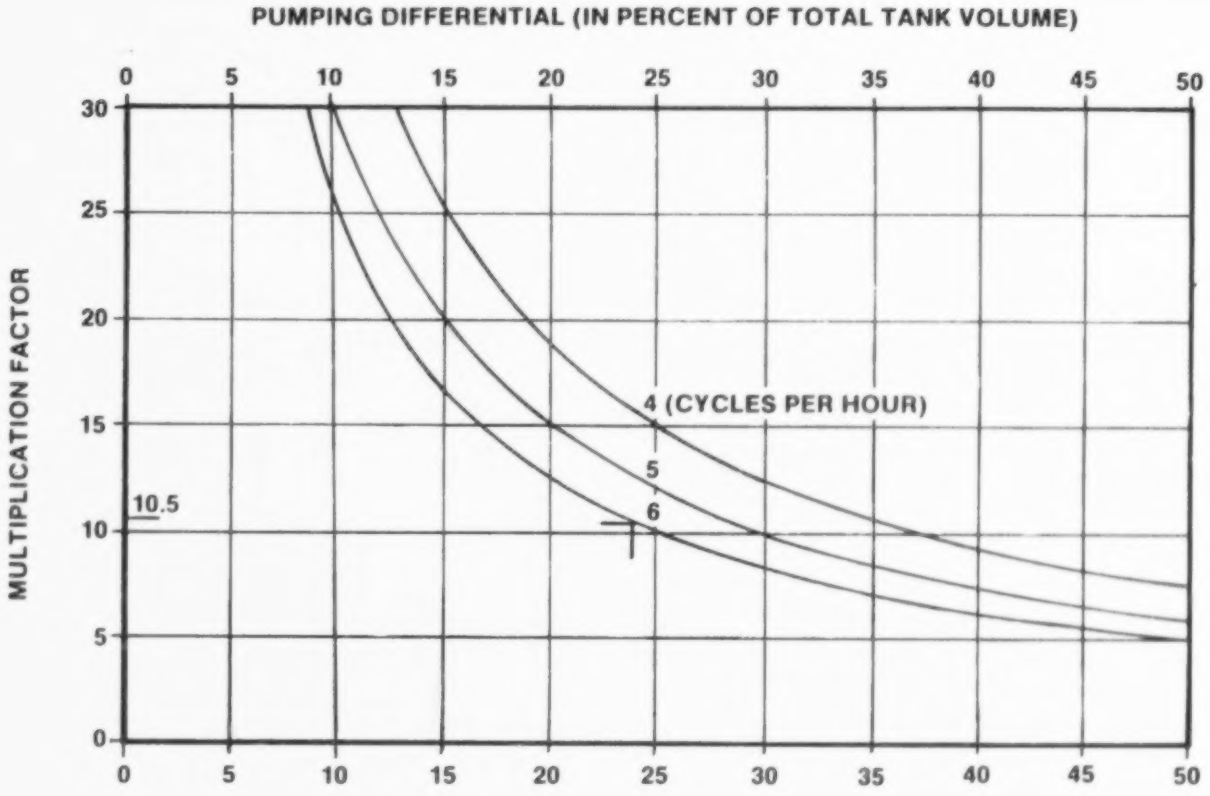

Fig. 3.57 Pressure tank volume requirements

at a minimum of 10 inches (25 cm) above the top rim of the outlet connection so that the possibility of air loss into the piping system will be minimized. This would require the HWL to be raised to the optimum level (27 inches or 67 cm).

Since we have the guidelines for our tank, let us proceed through an example of how we derived the HWL and check to see if the 20 psi (138 kPa or 1.4 kg/sq cm) differential is the most desirable for our situation.

EXAMPLE 1: PRESSURE DIFFERENTIAL AND EFFICIENCY DETERMINATION

Refer to Figure 3.56. Start at the point indicating a reserve of 10 percent by volume in the tank and follow this line horizontally to where it intersects the vertical 40 psi pressure line. Follow the closest pressure curve (in this case the 35 psi curve) to where it intersects the vertical 60 psi line. Then by interpolation determine the point which indicates that the water will occupy approximately 34 percent of the total tank capacity when the air has been compressed from 40 psi to 60 psi. The water level equivalent to 34 percent of the tank volume established the desired HWL.

The pumping differential is the difference in volume between the HWL and LWL in the tank. This differential expressed in percent also indicates the tank efficiency. Thus, 34 percent minus 10 percent indicates that the pumping differential is 24 percent of the total tank volume. With 24 percent of the total tank volume available for pumping, the tank efficiency also is 24 percent.

The actual HWL and LWL in the tank may now be established. The volume in a cylindrical, vertical tank is proportional to the height. Assume that a vertical tank is 72 inches high and the tank discharge is located in the tank bottom. Then the LWL is (10/100) 72 or 7.2 inches above the bottom of the tank and the HWL is (34/100) 72 or 24.28 inches above the bottom of the tank.

The volume in a cylindrical, horizontal tank is not proportional to the diameter (height) so volume height calculations must be made. These calculations will not be done here. To summarize, we have now established how to determine the LWL, the HWL, the pumping differential and the tank efficiency. The remaining consideration is for determining the most desirable operating pressure differential.

LWL
HWL
THINK EFFICIENCY
PUMPING DIFFERENTIAL
=
MOST DESIRABLE OPERATING PRESSURE DIFFERENTIAL

Assume, for example, that the pressure differential is to be 30 psi with 40 psi at LWL and 70 psi at HWL. Proceed as described above and determine that at 70 psi the water will occupy approximately 42 percent of the total tank volume. The pumping differential is 32 percent of the total tank volume and the tank efficiency is also 32 percent. This is a gain of 8 points over the 40 to 60 psi pressure selection. The pumping differential governs the size of the tank which will be required and also may effect the size of the pump because of the range in the pressure differential. Costs of each arrangement must be evaluated to determine the most efficient system.

EXAMPLE 2: TANK VOLUME DETERMINATION

The size of the tank is governed by both the established pumping volume differential and the number of pumping cycles desired. Experience indicates that the average number of pumping cycles need never be greater than six and very seldom is it necessary to provide for fewer than four cycles per hour. However, cases of 30 cycles per hour have been encountered.

The greater the number of pumping cycles, the smaller will be the size of the required tank. This must be given serious consideration when the first cost of an installation is of prime importance.

Fewer cycles will require the use of a larger tank but sometimes other important considerations besides first cost assume greater importance. Fewer pumping cycles are recommended for installations in hospitals, sanitariums and hotels where frequent starting and stopping may be annoying. Also when greater reserve is desired or required as, for example, when the installation is used for fire protection.

For example, to determine the tank size, let us assume the required pump capacity has been determined at 50 GPM, the pumping differential is 24 percent of the total tank capacity and that six pumping cycles per hour are desired.

Refer to Figure 3.57. This curve is based on the assumption that the average system demand is equivalent to one-half of the pump capacity. So with a pumping differential of 24 percent, we determine from the curve for six pumping cycles per hour that the multiplication factor is $10.5 \times 50 = 525$ gallons or the total volume for the required tank.

Some very small well pumping installations may be equipped with one or more small conventional vertical mounted hydropneumatic tanks *MANIFOLDED*[53] to the pump discharge. These tanks could range from 40 to 330 gallons (150 to 1250 liters) capacity and be equipped with a flexible or bag-type diaphragm.

3.16 WELL TESTING AND EVALUATION

3.160 Well Performance Testing

Well testing for quantity of water is an important phase of well construction. Information obtained during pumping tests provide data necessary to determine well and pump efficiency, pump installation depth settings, aquifer characteristics, capacity of the well, well recharge potential, and other factors which will be of use in the long term operation and maintenance of the well. The type of test for a specific well depends on intended use, size of well, and costs of the test. Performance tests should be consistent with the dimensions and capacity of the well and the rate at which it will be pumped when placed in service. Care must be taken to avoid excessive pumping rates which would damage the aquifer.

Depending on the size and proposed use of the well, performance testing may range from a simple bailing test of short duration to tests lasting 72 hours or longer. The driller normally has sole responsibility for small facilities. For larger wells, the operation will usually be under the direction of a competent engineer or geologist. In the latter case, the responsibility of the driller will be to operate the equipment and make the necessary measurements of flow and drawdown.

Measurements of water levels must be taken before, during and after performance testing. A static or non-pumping level must be established for comparison of the measurements made during pumping and recovery. This static level can be determined by making periodic measurements of water level for a period of time equal to, or longer than, the duration of the proposed test prior to its start. Water levels can be measured with a steel tape, by flagging (marking distances on) the bailer line, by an electric sounder, or by reading pressure on an air line. Recovery readings are also an important part of well testing and should be started immediately upon shutdown of the pumping test and continued at some specific interval.

With small-capacity wells which will operate intermittently or irregularly, testing should continue until an apparent stability of bailing or pumping level is achieved. Ideally, with large-capacity wells, pumping should be continued at a uniform rate of discharge until the *CONE OF INFLUENCE*[54] reflects any boundary condition which could affect future performance of the well. This probably will not exceed 24 hours for an artesian well, and 72 hours for a water table well. Large well testing should be under the supervision of someone with adequate qualifications and experience and may require use of observation wells.

Comprehensive aquifer tests require a minimum of one or two observation wells, depending on the purpose of the test results or the well. In typical situations, observation wells may be from 100 to 300 feet (30 to 90 m) from the production well and about the same depth. Observation wells may be smaller in diameter, however. For testing relatively thick artesian aquifers, observation well distances of 300 to 700 feet (90 to 210 m) from the pumped well are occasionally used.

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[53] *Manifold. A large pipe to which a series of smaller pipes are connected. Also called a HEADER.*

[54] *Cone of Influence. The depression, roughly conical in shape, produced in the water table by the pumping of water from a well.*

The amount and rate of drawdown and recovery of the water level with time are the most critical items of data needed to evaluate the initial efficiency of the well and the hydraulic characteristics of the aquifer.

3.161 Types of Pumping Tests

Several procedures for testing wells are available. They range from the very simple bailing procedure to the more complex step-continuous method.

3.1610 Bailing Test Method

The first step is to determine the *STATIC WATER LEVEL*[55] in the well. First, use a bailer of known volume to bail (remove water from) the well until the water level reaches a static level below which it cannot be lowered by further bailing. Lower the bailer until it just touches the water (if the bailer is dropped, it will make a splash as it hits the water surface). Mark the bailing line clearly at two points: one point at the top of the casing when the bailer is just on top of the static water level, and at a second point one bailer length above the first point. At even time intervals, lower the bailer until the second mark is just level with the top of the casing. The bailer must be full each trip. If the bailer is not full, increase the time per round trip until the bailer comes out full each time. Once this procedure continuously produces the same amount of water in equal time periods, the yield of that particular depth can be determined. The gallons per minute for that well at that depth is equal to the volume of the bailer (in gallons) divided by the time (in minutes) per round trip.

If the bailer cannot be completely submerged, the same procedure is used except that the volume must be measured and the time period adjusted for each trip until a constant volume is retrieved at regular intervals.

Bailing can be used successfully in low-yield wells, but other procedures are commonly used when the well has a high yield.

3.1611 Air Blow Test Method

This procedure requires the injection of air at the bottom of the well in sufficient quantity to blow water out of the well. As pressures must be high, some kind of deflector will be needed at the top of the well to capture and measure the water. Again, as with the bailing procedure, accurate measurements of water levels must be kept. For a measured period of time and volume of water taken out of the well, the rate of flow (GPM) can be calculated.

3.1612 Variable Rate Method

This method requires pumping the well at a series of constant rates and measuring the variation in drawdown during pumping. Install the pump at the lowest production point in the well and pump at a constant rate until the pump breaks suction. If the pump runs for more than 24 hours without breaking suction, further testing is probably not needed. (Essentially, the test would then be a constant rate test.) If the pump breaks suction, decrease the pumping rate until the water level in the well stabilizes approximately two (2) feet (0.6 m) above the pump intake. Then decrease the pump rate by 5 percent and pump until the water level has been stabilized for at least four (4) hours. The drawdown and pumping rate at that level are considered to be representative of the production rate and pumping level for that particular well.

3.1613 Constant Rate Method

When a well is pumped at a constant rate, the water level will continuously drop at a decreasing rate until a certain water level is reached and maintained. As the water level is lowered during the test, the flow rate of the pump may change due to the head/flow characteristics of the pump. Since this is a constant rate test, however, a valve for throttling and a meter for measuring flow must be used to assure that the pumping rate remains constant. Adjustments during testing should be made as needed to keep the flow constant.

Again, as in other test procedures, the static or nonpumping level should be established before testing starts. Frequent measurements should be made during the drawdown and recovery periods according to the following schedule: 0 to 10 minutes — every minute; 10 to 45 minutes — every 5 minutes; 45 minutes to 105 minutes — every 10 minutes; 105 minutes to 180 minutes — every 15 minutes; and from 3 hours to 24 hours — every hour. This schedule can be modified somewhat, but the purpose is to develop a good relationship between time and drawdown at a constant pumping rate.

If more than one drawdown test is to be conducted, the pump should be capable of providing flow rates from approximately 125 percent of design capacity to about 60 percent capacity. For a thorough understanding of the well and aquifer characteristics, more than one test is recommended. This procedure should result in some very accurate information about the well and its production capacity.

3.1614 Step-Continuous Composite Method

There are several variations or modifications of this test method. In this procedure, the well is tested at approximately ½, ¾, 1, and 1½ times the pump design capacity and usually runs for 24 hours or more. The test would start at ½ capacity for six hours, then ¾ capacity for 6 hours, then design capacity for 6 hours; and then 1½ capacity for 6 hours. Pumping times must be the same at each step in this test.

Also important to this test are the measurement periods which should be taken at even time intervals and in the same manner as for the constant rate method with one modification. Each time the pumping rate is increased, a new set of measurements is to be started. Recovery measurements should be taken once the drawdown is completed.

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[55] *Static Water Level. (1) The evaluation or level of the water table in a well when the pump is not operating, or (2) the level or elevation to which water would rise in a tube connected to an artesian aquifer, or basin, or conduit under pressure.*

This test is sometimes referred to as step drawdown or specific capacity test.

3.17 PUMP TESTING AND EVALUATION

3.170 Mechanical Wear of Pumps

Well pumps, like other pieces of moving machinery, are subject to some degree of mechanical wear. This wear can be accelerated if the pump was not correctly installed, the well is crooked, or the pump received inadequate lubrication. In addition, sand in the water can cause excessive and rapid wear of the bowl unit. If the well water is highly corrosive, a chemical reaction may occur that results in localized pitting and possible penetration of the well casing, bowl unit, or pump column pipe.

3.171 Guidelines for Testing

Well pump performance tests should be made on a routine basis to determine if excessive wear is occurring. These tests also reflect the yield characteristics of the well and are indicators of potential well problems. Well pumps should be tested once every other year. If there are clues that pump performance is rapidly changing, then more frequent testing is strongly advised. Tests should be run at about the same time each year to minimize the impact of seasonal variations in groundwater conditions. The same test point on the pump curve should be used. Therefore, if the discharge pressure at the pump was maintained at 50 psi (345 kPa or 3.5 kg/sq cm)(115.5 feet or 35.2 m of discharge head) during the previous test, then subsequent tests should also be made at the 50 psi point.

If the well pump installation is equipped with a flow meter, discharge pressure gage, and air line or probe device to measure water levels, then the operator can run one or more simple field tests to check well and pump performance. Tests for flow, pressure, drawdown, well yield, and gallons per minute per foot of drawdown can be readily made, and the results compared with previous tests to determine any changes in performance.

50 psi
(3.5 kg/sq cm)
(115.5 feet or
35

If the operator is unable to perform these tests, then assistance should be requested from the local power supplier. Many power companies offer this testing service free of charge. In larger communities some of the water well drillers or pump suppliers can perform this service for a small fee.

3.172 Operator Responsibility

Most small or medium-sized water companies are not equipped to perform full scale accurate field pump efficiency tests, nor is the average operator expected to have the knowledge and skills to perform these tests. However, a good operator should be capable of understanding the *TERMINOLOGY* (Section 3.173) and how the *CALCULATIONS* (Section 3.174) are made, and be able to evaluate the test results to the degree that the operator is aware when *PERFORMANCE VALUES* (Section 3.175) indicate that repair work to the pump is justified.

3.173 Terminology

The operator should have a working knowledge of the definitions in this section.

1. *STATIC WATER DEPTH.* The vertical distance in feet from the centerline of the pump discharge down to the surface level of the free pool while no water is being drawn from the pool or water table.
2. *DRAWDOWN.* The drop in the water table or level of water in the ground when water is being pumped from a well. The difference in feet between the pumping water level and the static water level.
3. *PUMPING WATER LEVEL.* The vertical distance in feet from the centerline of the pump discharge to the level of the free pool while the water is being drawn from the pool.
4. *DISCHARGE HEAD.* The pressure (in pounds per square inch or psi) measured at the centerline of discharge and very close to the discharge flange, converted into feet.

   Discharge, feet = (Pressure, lbs/sq in)(2.31 ft/psi)
5. *TOTAL PUMPING HEAD* (Field Head). The total pumping head equals the lift below the discharge plus the head (or pressure (psi) for water × 2.31 ft/psi) above the discharge. The latter item (head above the discharge) must include friction losses through any discharge pipe and fittings.
6. *TOTAL DYNAMIC HEAD* (Lab Head). The total head on the pump bowls and is equal to total pumping head plus column friction loss.

   Total Dynamic Head = Total Pumping Head + Column Friction Loss
7. *CAPACITY.* The rate of flow in liquid measure per unit of time (gallons per minute).
8. *LABORATORY EFFICIENCY* (Bowl Efficiency). This value is read directly from the performance curve based on total head in feet and pumping capacity in gallons per minute.
9. *LABORATORY HORSEPOWER.* The horsepower required at the impeller shaft to deliver the required capacity against the total dynamic head. Laboratory horsepower is calculated from the formula,

   $$\text{Laboratory HP} = \frac{(\text{Total Dynamic Head, ft})(\text{Capacity, GPM})(100\%)}{(3960)(\text{Laboratory Efficiency, \%})}$$
10. *COLUMN FRICTION LOSS.* The feet of head of friction loss in the column. This is dependent upon the length and size of column and shaft used. Column friction loss is tabulated in feet of head per hundred feet of column and shaft in column friction loss charts.
11. *SHAFT LOSS.* The energy lost in the shaft measured in horsepower and determined by the length and the size of shaft and the speed of the pump. To find the shaft loss, refer to shaft loss charts. The values on these charts are expressed in horsepower per hundred feet of shafting.
12. *BRAKE HORSEPOWER* (Field Horsepower). The horsepower required at the top of a pump shaft (input to a pump). The brake horsepower is the *SUM* of Laboratory Horsepower and Shaft Loss.

   Brake Horsepower = Laboratory Horsepower + Shaft Loss

13. *PUMP FIELD EFFICIENCY.* The efficiency of the complete pump with all losses between laboratory performance and field performance accounted for. Pump field efficiency is calculated by means of the formula,

$$\text{Pump Field Efficiency, \%} = \frac{(\text{Total Pumping Head, ft})(\text{Capacity, GPM})}{(3960)(\text{Brake Horsepower, HP})}(100\%)$$

14. *TOTAL PUMP THRUST.* The weight of the rotating parts in the pump bowls, the weight of the line shaft, and the hydraulic thrust of the water being pumped.

15. *THRUST BEARING LOSS.* The horsepower lost in the thrust bearings. This is dependent upon the type of thrust bearing and the total thrust load on the bearing. Bearing manufacturers indicate the loss in an angular contact ball bearing to be approximately 0.0075 HP per 100 RPM per 1000 lb thrust load.

16. *MOTOR EFFICIENCY.* The ratio of energy delivered by a motor to the energy supplied to it during a fixed period or cycle. Motor efficiency ratings will vary depending upon motor manufacturer and usually will range from 88.9 to 90.0 percent.

17. *OVERALL EFFICIENCY.* (Wire-to-Water Efficiency). The combined efficiency of a pump and motor together.

$$\text{Overall Efficiency} = (\text{Pump Field Efficiency})\,(\text{Motor Efficiency})$$

18. *INPUT HORSEPOWER.* The total power used in operating the pump and motor.

$$\text{Input Horsepower, HP} = \frac{(\text{Brake Horsepower, HP})}{(\text{Motor Efficiency, \%})}(100\%)$$

Figure 3.58 illustrates the basic configuration and mechanical apparatus used during the field testing of a well pump.

3.174 Calculations

Operators should be aware of the calculations involved in determining well-pump efficiencies. At first glance you may feel that the calculations are too difficult, but if taken step by step, you should be able to understand the procedure and, in time, become comfortable with the method.

As an example, let's calculate the *OVERALL PUMP EFFICIENCY* based on specifications as follows:

Known

Pump — 12 DKL, 4 stage, 1760 RPM
Capacity — 990 GPM
Static Water Level — 150 ft
Drawdown — 30 ft
Pumping Level — 180 ft
Total Head — 196 ft
BHP — 59.8 total
Column — 8 inches,
tube size is 2 inches
Motor — 60 HP, 4 pole, 440 volt,
3 phase, 60 cycle, vertical
hollow shaft
Shaft — size, 1¼ inches;
length, 200 ft

To calculate the *OVERALL PUMP EFFICIENCY,* try to obtain the above *"KNOWN"* information for the pump.

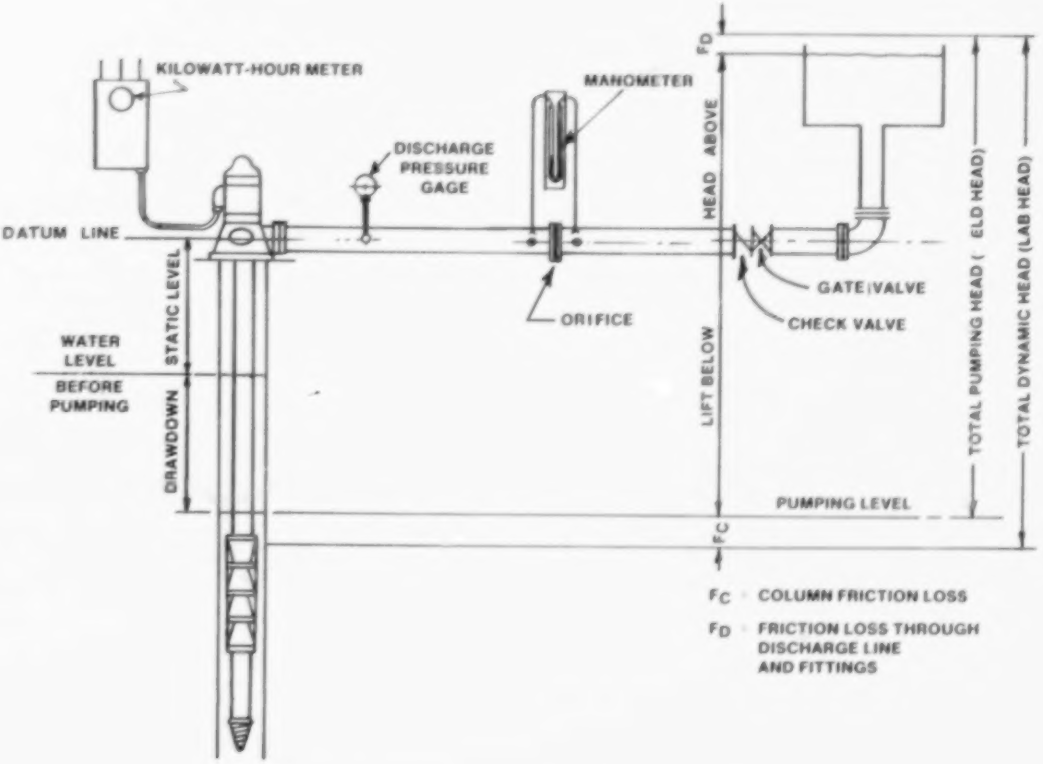
KILOWATT-HOUR METER
MANOMETER
DISCHARGE PRESSURE GAGE
DATUM LINE
STATIC LEVEL
WATER LEVEL BEFORE PUMPING
DRAWDOWN
ORIFICE
GATE VALVE
CHECK VALVE
FD
HEAD ABOVE
LIFT BELOW
PUMPING LEVEL
FC
TOTAL PUMPING HEAD (FIELD HEAD)
TOTAL DYNAMIC HEAD (LAB HEAD)
FC COLUMN FRICTION LOSS
FD FRICTION LOSS THROUGH DISCHARGE LINE AND FITTINGS

Fig. 3.58 Layout for field testing a well pump

Procedure to Completely Evaluate Pump Performance in Water Well Applications

	1. Static water level	150 ft	Measured from centerline of discharge head to water surface *BEFORE* the pump is started.
	2. Drawdown	30 ft	Measured from the water surface *BEFORE* the pump is started to the water surface after the pump has operated at a specified capacity for a specified time.
	3. Pumping level	180 ft	Sum of lines 1 and 2.
(a)	4. Discharge pressure ______ PSI × 2.31	10 ft	Gage reading in psi times 2.31 plus correction to centerline of discharge head. Correction is plus distance in feet from gage down to centerline of discharge head or minus distance in feet up to centerline of discharge head.
(b)	5. Field head	190 ft	Sum of lines 3 and 4.
	6. Column friction loss	6 ft	From Table 3.6 for a tube size of 1400 and a column of 2" × 8".
	7. Laboratory Head	196 ft	Sum of lines 5 and 6. Use this value for selection from curves in Figure 3.59. *NOTE:* Since we have a four stage pump, the TOTAL HEAD, ft/stage = 196 ft/4 stages = 49 ft/stage.
	8. Capacity	990 GPM	
(c)	9. Laboratory efficiency	84.5%	From curves in Figure 3.59 for a total head of 49 ft/stage and a capacity of 990 GPM. From a flow of 990 GPM draw a vertical line and head of 49 ft/stage draw a horizontal line. Where these lines meet, read the efficiency of 84.5%.
	10. Laboratory BHP	58.0 HP	$\frac{\text{Line 7} \times \text{Line 8} \times 100\%}{3960 \times \text{Line 9}}$ or $\text{BHP} = \frac{(196\text{ ft})(990\text{ GPM})(100\%)}{(3960)(84.5\%)}$
	11. Shaft loss	1.58 HP	From Table 3.7, for a shaft size of 1¼ inches and a shaft RPM of 1760, friction is 0.79 BHP/100 ft of shaft. Shaft loss for 200 feet of shaft is 1.58 HP.
(d)	12. Field BHP	59.58 HP	Sum of lines 10 and 11.
(e)	13. Field efficiency	79.7%	$\frac{\text{Line 5} \times \text{Line 8} \times 100\%}{3960^{*} \times \text{Line 12}}$ or $\quad {}^{*}3960 = \frac{33{,}000\text{ ft-lb/min-HP}}{8.34\text{ lbs/gal}}$ $\text{Efficiency, \%} = \frac{(190\text{ ft})(990\text{ GPM})(100\%)}{(3960)(59.58\text{ BHP})}$
(f)	14. Motor efficiency without thrust load	90%	From motor manufacturer.
	15. HP input to motor without thrust bearing losses	66.20 HP	$\frac{\text{Line 12} \times 100\%}{\text{Line 14}}$ or $\text{Input HP} = \frac{(59.58\text{ HP})(100\%)}{90\%}$
	16. Thrust bearing losses	0.42 HP	0.0075 HP per 100 RPM per 1000 lbs thrust ----- (g)
	17. Motor efficiency with thrust load	89.4%	$\frac{(\text{Line 12})(100\%)}{(\text{Line 15} + \text{Line 16})}$ or $\text{Efficiency, \%} = \frac{(59.58\text{ HP})(100\%)}{(66.20\text{ HP} + 0.42\text{ HP})}$
(h)	18. Overall plant efficiency	71.3%	$\frac{\text{Line 13} \times \text{Line 17}}{100\%}$ or $\text{Eff., \%} = \frac{(79.7\%)(89.4\%)}{100\%}$

(a) This is zero when pump discharges directly into the atmosphere through no more than 10 feet of horizontal discharge pipe.

(b) Sometimes called "total head." The term "field head" is to be preferred and its use is encouraged.

(c) Caution should be exercised in adjusting values shown on curves for number of stages used.

(d) This value should be used for selection of motors or gears, which should not be overloaded more than 15%.

(e) Frequently called "water-to-water" efficiency.

(f) These values are normally given for full, ¾ and ½ load, but vary so little near full load that the full load value can be used for slight under or overloads on the motor.

(g) Thrust load value is approximate only. The values obtained should be checked against thrust bearing capacities given for motor (or gear) to avoid overload. Load is weight of water in column.

(h) Frequently called "wire-to-water" efficiency.

TABLE 3.6 FRICTION LOSS TABLE FOR STANDARD PIPE COLUMN[a]

COLUMN FRICTION LOSS (IN FEET) PER100 FEET OF COLUMN

Column Size	4"			5"			6"			8"			10"				12"				14" OD			
Tube Size	1¼"	1½"	2"	1¼"	1½"	2"	1½"	2"	2½"	2"	2½"	3"	2"	2½"	3"	3½"	2"	2½"	3"	3½"	2½"	3"	3½"	4"
50[b]	.65	.86	1.6																					
75	1.3	1.7	3.3																					
100	2.2	2.8	5.3	.54	.65	.94																		
125	3.2	4.2	7.8	.81	.96	1.4																		
150	4.4	5.8		1.1	1.3	1.9																		
175	5.8	7.5		1.5	1.7	2.5																		
200	7.3	9.4		1.8	2.2	3.1	.73	.96	1.4															
225				2.3	2.7	3.9	.90	1.2	1.7															
250				2.7	3.3	4.7	1.1	1.4	2.0															
275				3.3	3.9	5.6	1.3	1.7	2.4															
300				3.8	4.5	6.4	1.5	2.0	2.8															
325				4.4	5.2	7.4	1.7	2.3	3.2															
350				5.0	6.0	8.4	2.0	2.6	3.6															
375				5.6	6.7	9.5	2.2	2.9	4.1															
400				6.3	7.5		2.5	3.3	4.6	.61	.74	1.0												
450				7.8	9.3		3.1	4.1	5.7	.77	.91	1.3												
500							3.7	5.0	6.9	.93	1.1	1.5												
550							4.4	5.8		1.1	1.3	1.8												
600							5.2	6.8		1.3	1.5	2.1												
650							6.0			1.5	1.8	2.5												
700										1.7	2.0	2.8												
750										1.9	2.3	3.2												
800										2.2	2.6	3.6	.57	.65	.77	.95								
850										2.4	2.9	4.0	.63	.72	.86	1.1								
900										2.7	3.2	4.5	.70	.80	.96	1.2								
950										2.9	3.5	4.9	.77	.88	1.1	1.3								
1000										3.2	3.9	5.4	.85	.97	1.2	1.4	.34	.38	.44	.50				
1200										4.5	5.4	7.6	1.2	1.4	1.6	2.0	.47	.54	.62	.71				
1400										6.0	7.2	10.	1.6	1.8	2.2	2.7	.62	.71	.82	.94				
1600										7.6	9.1	13.	2.0	2.3	2.8	3.4	.80	.90	1.1	1.2	.47	.53	.59	.67
1800										9.4	11.		2.5	2.8	3.4	4.3	.99	1.1	1.3	1.5	.58	.65	.73	.84
2000										11.	13.		3.0	3.5	4.2	5.2	1.2	1.4	1.6	1.8	.71	.80	.89	1.0
2200													3.6	4.1	5.0	6.1	1.4	1.6	1.9	2.1	.85	.95	1.1	1.2
2400													4.2	4.9	5.8	7.2	1.7	1.9	2.2	2.5	.99	1.1	1.2	1.4
2600													4.9	5.6	6.8	8.2	1.9	2.2	2.5	2.9	1.1	1.3	1.4	1.6
2800													5.6	6.4	7.8	9.6	2.2	2.5	2.8	3.3	1.3	1.5	1.6	1.9
3000													6.4	7.4	8.8	10.	2.5	2.9	3.3	3.8	1.5	1.7	1.9	2.1
3200																	2.8	3.2	3.7	4.3	1.7	1.9	2.1	2.4
3400																	3.2	3.6	4.2	4.8	1.9	2.1	2.4	2.7
3600																	3.5	4.0	4.7	5.3	2.1	2.4	2.6	2.9
3800																	3.9	4.4	5.1	5.9	2.3	2.6	2.9	3.3
4000																	4.3	4.9	5.6	6.4	2.5	2.9	3.2	3.6
4200																	4.7	5.3	6.2	7.1	2.8	3.1	3.5	3.9
4400																	5.1	5.8	6.7	7.7	3.0	3.4	3.8	4.3
4600																	5.6	6.3	7.4	8.4	3.3	3.7	4.1	4.6
4800																	6.0	6.8	7.9	9.0	3.5	4.0	4.4	5.0
5000																					3.8	4.3	4.8	5.4
5200																					4.2	4.7	5.2	5.9
5500																					4.6	5.1	5.7	6.4
5750																					5.0	5.5	6.2	6.9
6000																					5.4	6.0	6.7	

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[a] Floway Turbine Pumps, Peabody Floway Inc., Fresno, CA.

[b] This column is flow in GPM

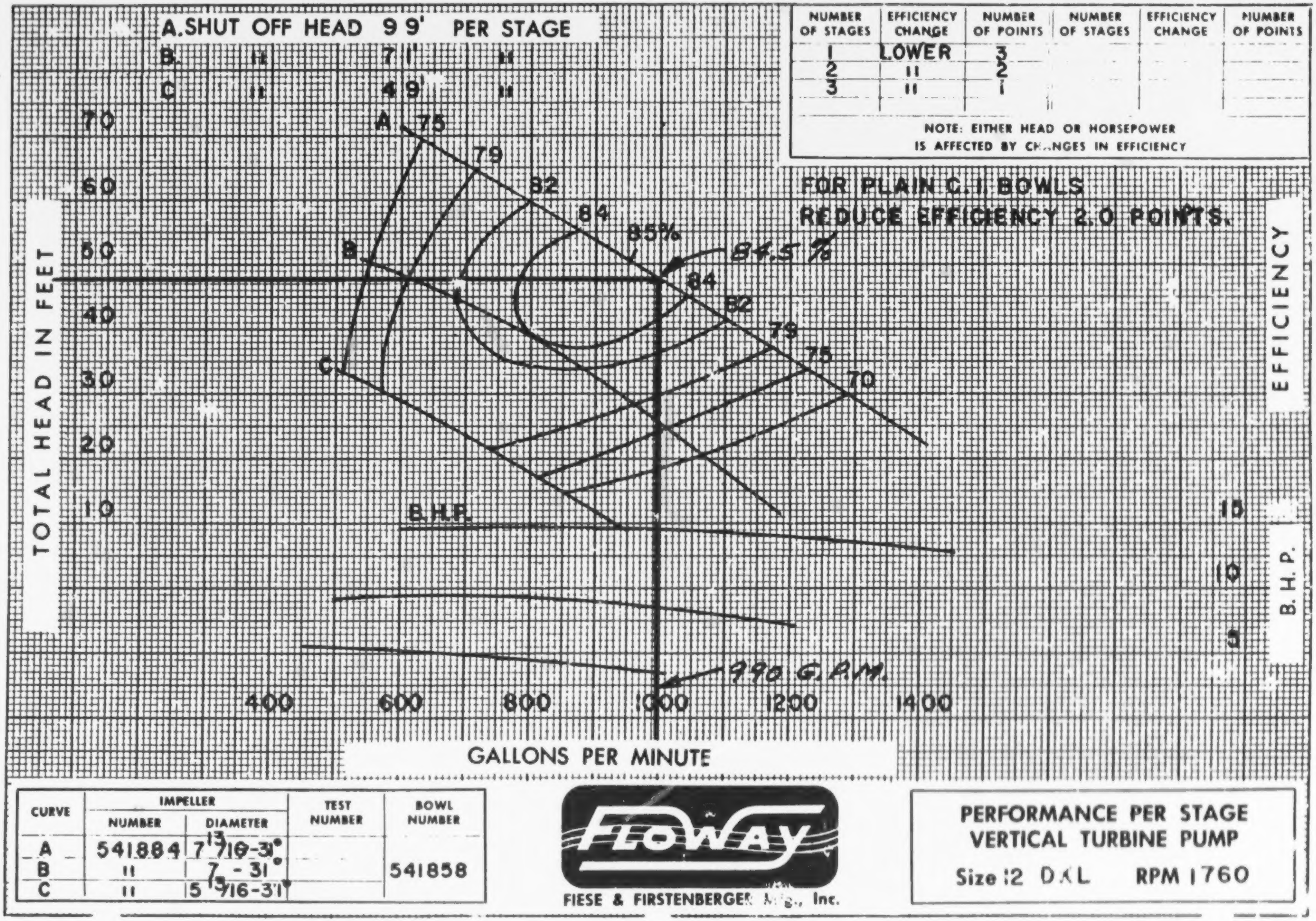

Fig. 3.59 Performance per stage for vertical turbine pump

(Permission of Peabody Floway Inc., Fresno, CA)

TABLE 3.7 MECHANICAL FRICTION IN BHP PER 100 FEET OF SHAFT[a]

Inches Shaft Size	R. P. M. of Shaft								
	3460	2900	1760	1450	1160	960	860	720	690
¾	.60	.51	.31	.26	.20	.17			
1	1.05	.87	.53	.44	.35	.29	.26	.25	
1¼	1.60	1.33	.79	.67	.52	.44	.39	.34	
1½	2.20	1.90	1.14	.96	.74	.63	.56	.47	.44
1¾		2.50	1.50	1.25	.97	.83	.74	.64	.59
2			1.90	1.60	1.25	1.05	.95	.81	.76
2¼			2.40	2.00	1.55	1.35	1.20	1.00	.96

The horsepower loss due to mechanical friction, in column shaft rotation may be determined from the chart

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[a] Floway Turbine Pumps, Peabody Floway Inc., Fresno, CA.

3.175 Performance Values

The operator should be able to evaluate the pump performance test.

Figure 3.60 is a copy of a typical well pump test report. Using the data and computations shown on this report, we can make a good performance evaluation of this well pumping facility. Under remarks, the test engineer has already summarized the general conditions at this pumping facility: Two important items to consider on this report are: (1) the *OVERALL PLANT EFFICIENCY*, and (2) the *HORSEPOWER INPUT TO MOTOR*. Let us look at these two items in more detail.

1. *OVERALL PLANT EFFICIENCY (O.P.E.)*

   The O.P.E. is 62.8 percent and the test engineer has commented that this is fair and rightly so; a new 100 HP pumping plant would have an O.P.E. in excess of 72 percent. This plant, at 62.8 percent, is fair but should be tested annually for a further reduction in O.P.E. If the O.P.E. was between 50 to 58 percent, then you should consider replacing the pumping unit.

2. *HORSEPOWER INPUT TO MOTOR*

   The test engineer has noted that the motor is underloaded approximately 16 percent at 91.6 HP. If we assume that the correct bowl unit was installed at this plant, then the horsepower input should be from 100 to 110 HP. This report does not indicate if the bowl unit is a *SEMI-OPEN* or *FULLY ENCLOSED* impeller type. If the impeller is *SEMI-OPEN*, then it would have been possible to adjust the impeller clearance and perhaps increase the load on the motor which in turn would also raise the O.P.E. to a higher value. If the impeller was *FULLY ENCLOSED*, then no impeller adjustment could be made, and we would assume that the reason for the fair O.P.E. and the 16 percent motor underload is a result of wear to the pumping unit.

Two other important factors must be considered in the overall performance evaluation of a well pumping station; (1) the frequency of use, and (2) the energy use. These two factors are interrelated and should be carefully considered before determining if pump replacement is economically justified.

1. *FREQUENCY OF USE*

   If the pumping station is used only to meet peak summer demands or emergencies, then an O.P.E. rating between 50 to 55 percent may be acceptable. An O.P.E. rating under 50 percent would qualify almost any deep-well turbine pump for replacement.

   If the pumping station is a lead facility operating between 20 to 40 percent of the time, then an O.P.E. rating between 55 to 60 percent could justify replacing the pump.

2. *ENERGY USE*

   The high cost of energy may be the major factor in determining when a pumping unit should be replaced.

   Using the pump values as shown on the pump test report (Figure 3.60) and the energy use data (from Table 3.8), we can estimate power consumption for various O.P.E. ratings.

   Assuming that the well pump in this report is a lead pump operating 30 percent of the time and we use O.P.E. ratings of 72 percent (new facility), 63 percent (pump under evaluation) and 52 percent (a worn pump), then we can estimate what the annual energy use would be based on the above mentioned O.P.E. ratings. The calculations are as follows:

Overall Efficiency Pump Unit	Kilowatts per 1000 Gallons at one foot T.H.*		Total Lift in feet		Kilowatts per 1000 Gallons at Total Lift
72%	.00435	×	173	=	.753
63%	.00498	×	173	=	.844
52%	.00603	×	173	=	1.040

* Values from Table 3.8.

— THEREFORE —

30 percent pumping time for 1 year (365 days × 24 hr/day × 60 min/hr × 0.30 = 157,680 minutes) × pumping rate (1319 GPM) = 207,979,920 gallons or 207,980 thousand gallons pumped in 1 year. So, then the three O.P.E. ratings we are using, we will have yearly power consumptions as follows:

TABLE 3.8 ENERGY USE DATA

Overall Efficiency Pump Unit[a]	Kilowatts per 1000 Gallons at one foot T.H.	Overall Efficiency Pump Unit[a]	Kilowatts per 1000 Gallons at one foot T.H.	Overall Efficiency Pump Unit[a]	Kilowatts per 1000 Gallons at one foot T.H.
32	.00980	52	.00603	72	.00435
33	.00951	53	.00592	73	.00430
34	.00922	54	.00581	74	.00424
35	.00896	55	.00570	75	.00418
36	.00871	56	.00560	76	.00413
37	.00848	57	.00550	77	.00407
38	.00826	58	.00541	78	.00402
39	.00804	59	.00532	79	.00397
40	.00784	60	.00523	80	.00392
41	.00765	61	.00514	81	.00387
42	.00747	62	.00506	82	.00382
43	.00730	63	.00498	83	.00378
44	.00713	64	.00490	84	.00373
45	.00697	65	.00482	85	.00369
46	.00682	66	.00475	86	.00365
47	.00667	67	.00468	87	.00360
48	.00653	68	.00461	88	.00356
49	.00640	69	.00454	89	.00352
50	.00627	70	.00448	90	.00348
51	.00615	71	.00442		

[a] Overall efficiency as indicated is the input-output efficiency including all losses in the pump unit, pumping 1000 gallons of clear water one foot total head. Therefore, in determining the kilowatts per 100 gallons pumped, it is only necessary to multiply the factor corresponding to the overall efficiency by the number of feet head at which the total dynamic head has been calculated. Example:

Assume an overall efficiency of 65% and a total head of 200 feet.
Kilowatts per 1000 gallons = .00482 × 200 = .964

Source: *ENGINEERING DATA*, Peabody Floway Inc., Fresno, CA.)

(1) O.P.E.	(2) Annual Water Production in 1000 Gallons	(3) Kilowatts per 1000 Gallons at Total Lift	(4) Annual Kilowatts Used*	(5) % Additional Energy Required**
72%	207,980	.753	156,609	0
63%	207,980	.844	175,535	12.08
52%	207,980	1.040	216,299	38.11

* (2)(3) = (207,980)(0.753) = 156,609

** $\frac{((4) - 156{,}609)(100\%)}{156{,}609} = \frac{(175{,}535 - 156{,}609)(100\%)}{156{,}609} = 12.08\%$

Using the values in column (5) we can see that the well pump tested in Figure 3.58 with an O.P.E. of 68 percent will use *12.08* percent more energy than a new or reconditioned pump with an O.P.E. of 72 percent. If the O.P.E. drops to 52 percent, then *38.11* percent more energy would be used to pump the same amount of water. When we compare the additional energy used by a worn pump with today's high cost of energy we can readily understand the importance of routine pump performance tests and evaluation. A good operator should be capable of evaluating well pumping plants and determining when it is economically justified to replace a worn pumping unit.

3.18 ABANDONING AND PLUGGING WELLS

3.180 Reasons for Abandoning and Plugging

Eventually a water well reaches the end of its useful life. Many are simply abandoned and become a safety hazard and a threat to the groundwater supply.

A well that is no longer useful must be properly abandoned and plugged:

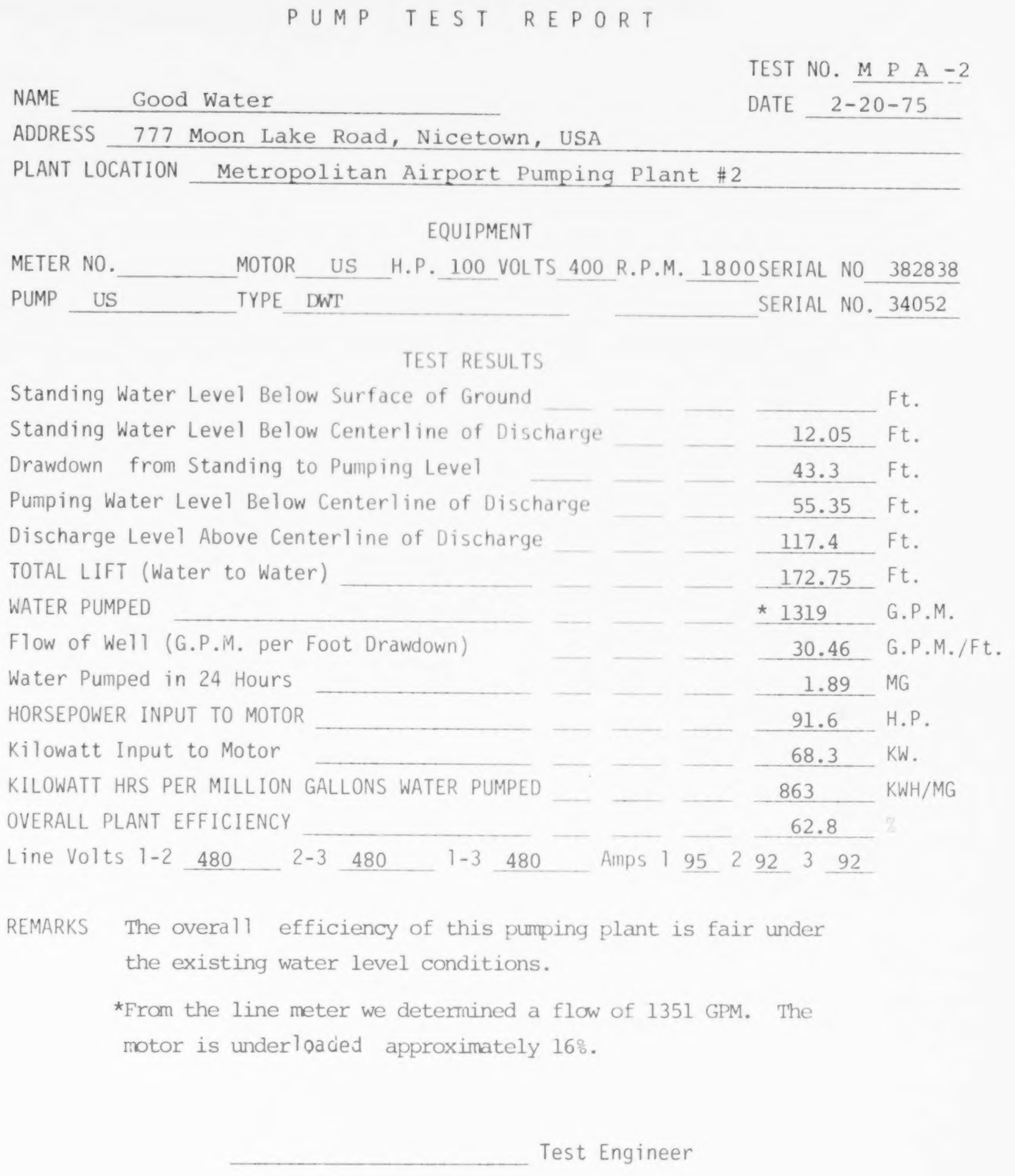
1. To assure that the groundwater supply is protected and preserved for further use,
2. To eliminate the potential physical hazard to people, and
3. To protect nearby wells from contamination.

Private wells that no longer serve any useful purpose should also be abandoned and plugged. When a home is connected to a public water supply, the old well could cause *CROSS-CONNECTION*[56] problems if it is not adequately and permanently disconnected from the public water system.

The concept that we all have an interest in our groundwater resources and, therefore, an obligation to protect them for their present and continued use, is a fundamental

---

[56] *Cross-Connection. A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.*



PUMP TEST REPORT

TEST NO. M P A -2
NAME Good Water
DATE 2-20-75
ADDRESS 777 Moon Lake Road, Nicetown, USA
PLANT LOCATION Metropolitan Airport Pumping Plant #2

EQUIPMENT

METER NO. ______ MOTOR US H.P. 100 VOLTS 400 R.P.M. 1800 SERIAL NO 382838
PUMP US TYPE DWT ______ SERIAL NO. 34052

TEST RESULTS

Standing Water Level Below Surface of Ground		Ft.
Standing Water Level Below Centerline of Discharge	12.05	Ft.
Drawdown from Standing to Pumping Level	43.3	Ft.
Pumping Water Level Below Centerline of Discharge	55.35	Ft.
Discharge Level Above Centerline of Discharge	117.4	Ft.
TOTAL LIFT (Water to Water)	172.75	Ft.
WATER PUMPED	* 1319	G.P.M.
Flow of Well (G.P.M. per Foot Drawdown)	30.46	G.P.M./Ft.
Water Pumped in 24 Hours	1.89	MG
HORSEPOWER INPUT TO MOTOR	91.6	H.P.
Kilowatt Input to Motor	68.3	KW.
KILOWATT HRS PER MILLION GALLONS WATER PUMPED	863	KWH/MG
OVERALL PLANT EFFICIENCY	62.8	%

Line Volts 1-2 480 2-3 480 1-3 480 Amps 1 95 2 92 3 92

REMARKS The overall efficiency of this pumping plant is fair under the existing water level conditions.

*From the line meter we determined a flow of 1351 GPM. The motor is underloaded approximately 16%.

______ Test Engineer

Fig. 3.60 Well pump test report

one. This concept holds true whether the issue is construction or abandoning of a well.

3.181 *Objectives*

All "abandoned" wells should be properly plugged. A well could be generally classified as abandoned when it has not been used for a period of one year, the pumping unit has been removed, and the well serves no useful purpose. The objective of abandoning and plugging is to restore as nearly as practical, those subsurface conditions which existed prior to the construction of the well. Another important objective is to prevent the possible cross-contamination between different aquifers.

3.182 *Evaluations*

An investigation should be made to determine the condition of the well to be abandoned and plugged, details of its construction, and whether there are obstructions or objects in the well that may hinder the filling and sealing process. Visual inspection using downhole television and photography can be very useful tools in determining the overall condition of a well.

3.183 *Permits*

In most cases, a permit is required before a well can be abandoned and plugged. This permit may be issued at the local, state, or federal level, and its purpose is to set forth well abandoning and plugging guidelines and inspection to assure the protection of the groundwater basin. In certain areas, the protection of the groundwater basin is especially important.

As an example, within California alone there are 400 significant groundwater basins; of these, many have been identified as critical basins where the interchange of water between aquifers will result in a significant deterioration of the quality of water in one or more aquifers. Problem areas occur in coastal aquifers that have been invaded by sea water, and in areas where saline water underlays an area at varying depths.

3.184 *Abandoning and Plugging Guidelines*

Abandoning and plugging procedures and methods will vary according to whether the well is situated in (1) unconsolidated material in an unconfined groundwater zone, (2) creviced or fractured rock, (3) noncreviced consolidated formation, or (4) where several aquifers or formations have been penetrated and an aquifer seal is required to prevent the vertical movement of water between aquifers.

The enforcing agency will often establish the procedures to be followed when abandoning and plugging a well. In some cases, the water purveyor will be required to seek the advice of a geologist or a well expert to determine the appropriate methods to use.

Following this paragraph is a brief procedure for abandoning and plugging a well. This procedure reflects the desired end results and may be applicable for many old wells that are likely to be abandoned and plugged. Remember that this is a general guideline only, and that local requirements and ordinances will prevail, plus special conditions that may be encountered due to the construction of the well, and/or the formations penetrated.

1. The well to be abandoned and plugged must be cleaned of foreign debris. In many cases this will require the use of a small drilling rig.
2. Drill out the old well to the estimated depth of its original construction, but in no case less than 100 feet (30 m).
3. With the drilling rig in position, air pump the well for two hours at its maximum capacity or at a minimum rate of 100 GPM (6 liters/sec).
4. Disinfect the well by adding a chlorine compound to produce a chlorine dose of 200 mg/*L*. If a dry chemical is used, it should be mixed with water to form a chlorine solution prior to placing it into the well.
5. Fill the well to within 25 feet (7.5 m) of ground elevation with suitable fill materials such as neat cement, cement grout, concrete, bentonite clay, or clean sand.
6. Excavate a hole around the well casing to a depth of 5 feet (1.5 m) and cut off the well casing six inches (150 mm) above the bottom of the excavation.
7. Fill the upper portion of the well with cement grout or concrete and allow to spill over into the excavation to form a cap at least one-foot (0.3 m) thick.
8. After the sealing material has set, fill the excavation with native soil.

See Figures 3.61, 3.62 and 3.63 for cross-sectional views of properly abandoned and plugged wells.

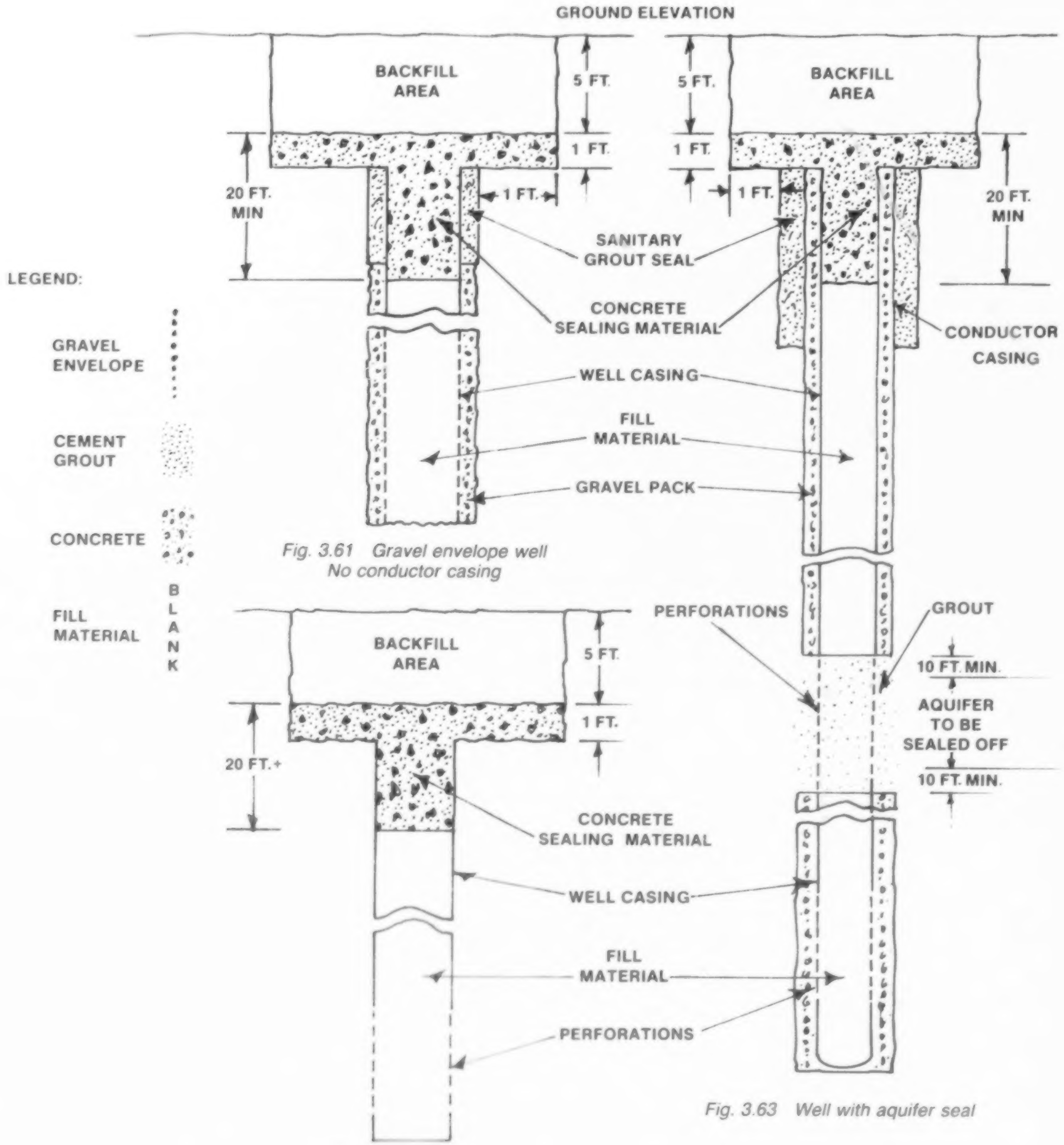

GROUND ELEVATION
BACKFILL AREA
5 FT.
1 FT.
20 FT. MIN
1 FT.
BACKFILL AREA
5 FT.
1 FT.
1 FT.
20 FT. MIN
SANITARY GROUT SEAL
CONCRETE SEALING MATERIAL
CONDUCTOR CASING
WELL CASING
FILL MATERIAL
GRAVEL PACK
LEGEND:
GRAVEL ENVELOPE
CEMENT GROUT
CONCRETE
FILL MATERIAL
BLANK
PERFORATIONS
GROUT
10 FT. MIN.
AQUIFER TO BE SEALED OFF
10 FT. MIN.
BACKFILL AREA
5 FT.
1 FT.
20 FT.+
CONCRETE SEALING MATERIAL
WELL CASING
FILL MATERIAL
PERFORATIONS

Fig. 3.61 Gravel envelope well
No conductor casing

Fig. 3.62 Old cable tool well
No sanitary grout seal

Fig. 3.63 Well with aquifer seal

CHAPTER 4

SMALL WATER TREATMENT PLANTS

by

Jess Morehouse

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OBJECTIVES

Chapter 4. SMALL WATER TREATMENT PLANTS

Following completion of Chapter 4, you should be able to:

1. Explain the importance of small water treatment plants;
2. Operate and maintain treatment processes for
   a. Coagulation,
   b. Flocculation,
   c. Settling,
   d. Filtration,
   e. Disinfection,
   f. Corrosion control,
   g. Solids contact units,
   h. Iron and manganese control, and
   i. Softening; and
3. Safely perform the duties of an operator.

GLOSSARY

Chapter 4. SMALL WATER TREATMENT PLANTS

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ADSORPTION (add-SORP-shun) ADSORPTION

The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AERATION (air-A-shun) AERATION

The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.

ALKALINITY (AL-ka-LIN-ity) ALKALINITY

The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

BACKWASHING BACKWASHING

The process of reversing the flow of water back through the filter media to remove entrapped solids.

BREAKPOINT CHLORINATION BREAKPOINT CHLORINATION

Addition of chlorine to water until chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT

An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

A system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic and concentrates corrosion on auxiliary anodic parts used for the purpose of corrosion instead of the structure.

CHLORINATOR (KLOR-uh-NAY-ter) CHLORINATOR

A metering device which is used to add chlorine to water.

CLEAR WELL CLEAR WELL

A reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand. Also used to provide chlorine contact time for disinfection.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The clumping together of very fine particles into large particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

DIATOMACEOUS EARTH (DYE-uh-toe-MAY-shus) DIATOMACEOUS EARTH

A fine, siliceous (made of silica) "earth" composed mainly of the skeletal remains of diatoms.

DIATOMS (DYE-uh-toms) DIATOMS

Unicellular (single cell), microscopic algae with a rigid (box-like internal structure consisting of many silica.

ELECTROCHEMICAL REACTION ELECTROCHEMICAL REACTION

Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action). In corrosion, a chemical reaction is accompanied by the flow of electrons through a metallic path. The electron flow may come from an external force and cause the reaction, such as electrolysis caused by a D.C. (direct current) electric railway or the electron flow may be caused by a chemical reaction as in the galvanic action of a flashlight dry cell.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles to form larger particles by a process of gentle mixing.

GARNET (GAR-nit) GARNET

A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

GREENSAND GREENSAND

A sand which looks like ordinary filter sand except that it is green in color. This sand is a natural ion exchange mineral which is capable of softening water.

HYPOCHLORINATOR (hi-poe-KLOR-i-NAY-tor) HYPOCHLORINATOR

A chlorine pump, chemical feed pump or device used to dispense chlorine solutions made from hypochlorites such as bleach (sodium hypochlorite) or calcium hypochlorite into the water being treated.

MONOMER (MON-o-MER) MONOMER

A molecule of low molecular weight capable of reacting with identical or different monomers to form polymers.

MUDBALLS MUDBALLS

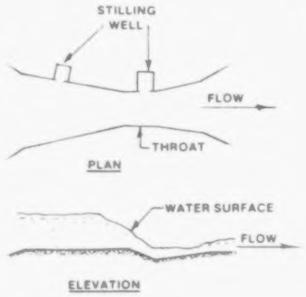
Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. This material forms in filters and gradually increases in size when not removed by the backwashing process.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

PARSHALL FLUME PARSHALL FLUME

A device used to measure the flow in an open channel. The flume narrows to a throat of fixed dimensions and then expands again. The rate of flow can be calculated by measuring the difference in head (pressure) before and at the throat of the flume.



POLYELECTROLYTE (POLLY-ee-LECK-tro-lite) POLYELECTROLYTE

A high-molecular-weight (relatively heavy) substance having points of positive or negative electrical charges that is formed by either natural or man-made processes. Natural polyelectrolytes may be of biological origin or derived from starch products and cellulose derivatives. Man-made polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. Often called a POLYMER.

POLYMER POLYMER

A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

To separate (a substance) out in solid form from a solution, as by the use of a reagent. The substance precipitated.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

RECARBONATION (re-CAR-bun-NAY-shun) RECARBONATION

A process in which carbon dioxide is bubbled into the water being treated to lower the pH. The pH may also be lowered by the addition of acid. Recarbonation is the final stage in the lime-soda ash softening process. This process converts carbonate ions to bicarbonate ions and stabilizes the solution against the precipitation of carbonate compounds.

RELIQUEFACTION (re-LICK-we-FACK-shun) RELIQUEFACTION

The return of a gas to the liquid state; for example, a condensation of chlorine gas to return to its liquid form by cooling.

SHORT-CIRCUITING SHORT-CIRCUITING

A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

SLUDGE (sluj) SLUDGE

The settleable solids separated from water during processing.

SLURRY (SLUR-ee) SLURRY

A water mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SUPERCHLORINATION SUPERCHLORINATION

Chlorination with doses that are deliberately selected to produced free or combined residuals so large as to require dechlorination.

TRIHALOMETHANES (tri-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY UNITS (TU) TURBIDITY UNITS (TU)

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

ZEOLITE ZEOLITE

A type of ion exchange material used to soften water. Natural zeolites are siliceous compounds (made of silica) which remove calcium and magnesium from hard water and replace them with sodium. Synthetic or organic zeolites are ion exchange materials which remove calcium or magnesium and replace them with either sodium or hydrogen.

BACKWASHING

CHAPTER 4. SMALL WATER TREATMENT PLANTS

(Lesson 1 of 2 Lessons)

4.0 IMPORTANCE OF SMALL WATER TREATMENT PLANTS

4.00 Need for Effective O&M

Small water treatment plants (Figure 4.1) are much more numerous than large plants. Most water treatment plants are small facilities that supply water to systems ranging in size from a few connections up to several hundred connections. For every large water plant serving a large population in a big service area, there are probably several hundred small plants that serve groups of people in small communities, subdivisions, commercial properties, resorts and summer camps.

The volume of water produced by these small plants may vary from only fifteen gallons per minute (one liter per second) up to a few hundred gallons per minute. Regardless of the amount of water a plant produces, it must be properly operated to produce safe drinking water. Small plants face many of the same problems as larger ones but often the small plant does not perform as well because of poor design, poor operation, poor maintenance, inadequate budgets and other causes. However, it is very important that these small plants be operated effectively because many people depend on them for their daily home water supply and many others drink the water on an occasional or intermittent basis.

Small water treatment plants are common because the source of water for many small communities requires treatment. Surface waters must be clarified and disinfected to insure it is safe and to make it pleasing to the senses. Many groundwater sources require treatment for disinfection or for removal of undesirable minerals and gases in solution. Thus, almost any source of supply is likely to require treatment of some kind. The water supply that needs no treatment whatsoever is increasingly rare today as polluted waters are found everywhere and as standards for domestic water quality become more restrictive.

4.01 Surface Waters

A typical small water treatment system for treating surface waters may include any or all of the following components (see Figure 4.2).

1. *RAW WATER STORAGE*

   Surface water sources are frequently developed from lakes, ponds, or reservoirs. These impoundments provide storage for the raw, untreated water and frequently are helpful to the treatment processes. One important effect of raw water storage is to slow the rate of change in water quality that occurs in surface water sources and to reduce the magnitude of the change. For instance, a rainstorm may cause a sudden, drastic change in the turbidity or the mineral composition of a stream source. If the stream flows into a large reservoir, however, the water quality changes much more slowly and less drastically than in the stream. The overall effect is to make available a raw water supply from the reservoir whose quality is more uniform and consistent. This uniform water quality will make any water treatment plant easier to operate and more effective.

   If the water source is a canal or pipeline that is subject to shutdowns or outages, a raw water reservoir is necessary to keep the treatment plant in operation. Otherwise the plant must stop operating whenever the water source is out of service.

Fig. 4.1 Small water treatment plants

(Permission of Watermasters, Inc., Burlingame, California)

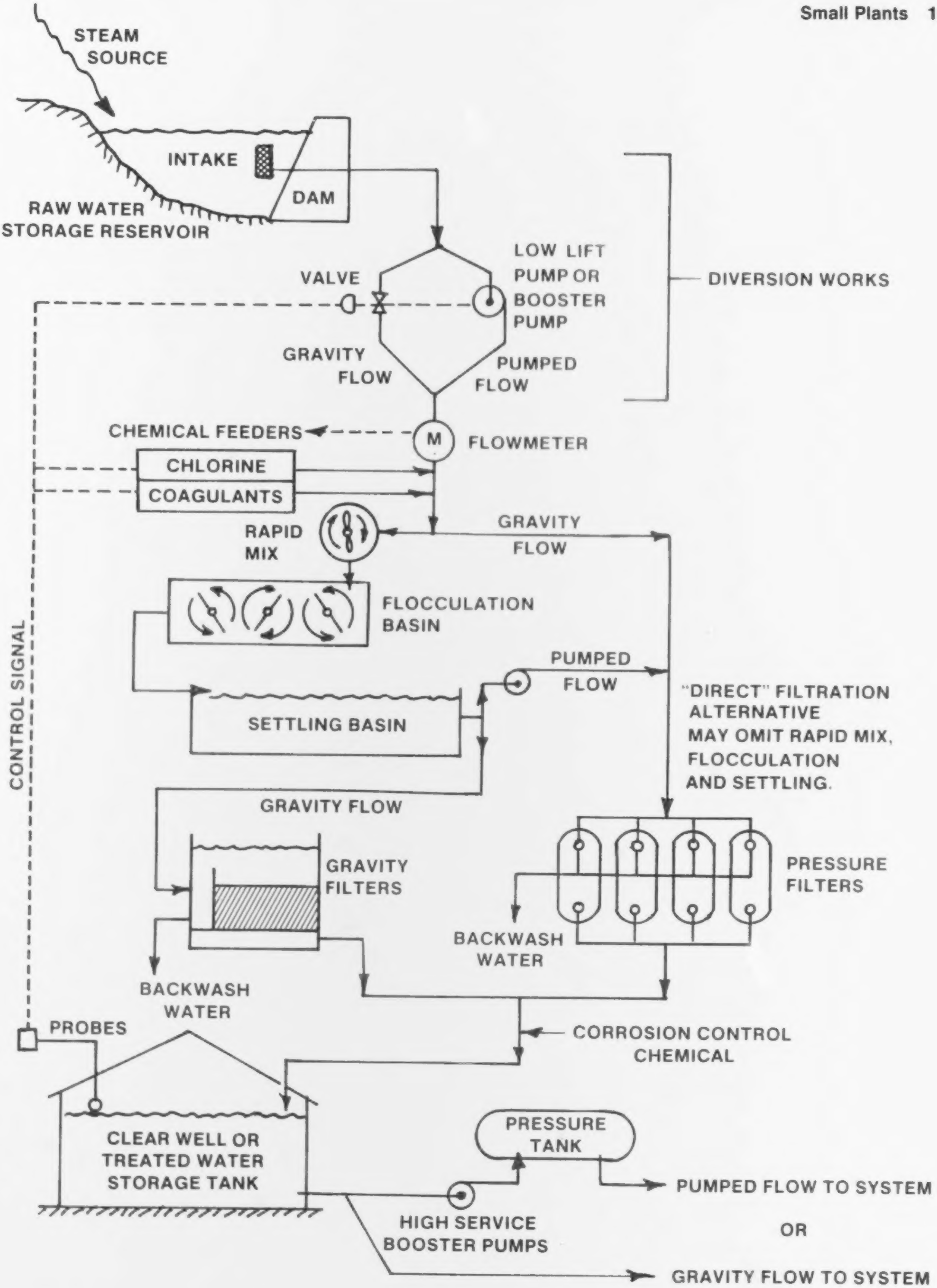

STEAM SOURCE
INTAKE
DAM
RAW WATER STORAGE RESERVOIR
LOW LIFT PUMP OR BOOSTER PUMP
DIVERSION WORKS
VALVE
GRAVITY FLOW
PUMPED FLOW
CHEMICAL FEEDERS
M
FLOWMETER
CHLORINE
COAGULANTS
RAPID MIX
GRAVITY FLOW
FLOCCULATION BASIN
CONTROL SIGNAL
PUMPED FLOW
SETTLING BASIN
"DIRECT" FILTRATION ALTERNATIVE
MAY OMIT RAPID MIX, FLOCCULATION AND SETTLING.
GRAVITY FLOW
GRAVITY FILTERS
PRESSURE FILTERS
BACKWASH WATER
BACKWASH WATER
PROBES
CORROSION CONTROL CHEMICAL
CLEAR WELL OR TREATED WATER STORAGE TANK
PRESSURE TANK
PUMPED FLOW TO SYSTEM
OR
HIGH SERVICE BOOSTER PUMPS
GRAVITY FLOW TO SYSTEM

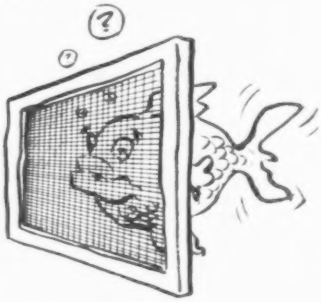
Fig. 4.2 Parts of a typical small water treatment system

2. *DIVERSION WORKS*

   The diversion works consist of all the facilities used to divert water from the source into the treatment plant. These facilities may include a diversion dam, screens to exclude fish and trash, an intake pipe or structure, pumping equipment, piping or conduits to convey the water to the plant, and valves or gates to control the flow of water.

3. *FLOW MEASUREMENT*

   A flow meter of some type is essential for proper operation of even the smallest water treatment plant. The meter should be the type that indicates both the instantaneous rate of flow as well as the total quantity of water that has flowed through it. The meter must be accurate enough to allow the operator to feed the proper chemical dosages. A fine screen or *WYE STRAINER*[1] should be installed upstream from the meter to keep it from being clogged or damaged by trash or rocks.



4. *DISINFECTION*

   Chlorine is the chemical frequently applied to the water for disinfection. Prechlorination is often used because as the water flows through the treatment units, it receives the maximum contact time before reaching consumers. A chlorine residual in water flowing through the plant also discourages growths or organisms and helps keep the filter media and other treatment equipment clean and free of organic growths. Prechlorination should not be used if natural organics are in the water and the formation of *TRIHALOMETHANES*[2] is a problem.

5. *COAGULATION*

   COAGULATION[3] facilities include the chemical feeding equipment for injecting coagulants and equipment for providing rapid mixing of the chemicals with the water.

6. *FLOCCULATION*

   Flocculation facilities include equipment for slowly mixing the water to promote growth of floc particles that will settle quickly or be removed by filtration.

7. *SETTLING* (sedimentation)

   Settling allows suspended matter to be separated from the water by gravity. A very large portion of the suspended matter is usually removed in the settling tanks.

8. *FILTRATION*

   Filters remove most of the suspended matter remaining in the water after settling.

9. *CORROSION CONTROL*

   Corrosion control treatment is used to stabilize the chemical nature of the water and make it less aggressive toward the materials used in pipelines, storage reservoirs and customer appliances.

10. *TREATED WATER STORAGE*

    Storage reservoirs for treated water may be installed either at the treatment plant *(CLEAR WELL*[4]*)* or out in the distribution system. Such reservoirs allow the treatment plant to be of smaller capacity than would otherwise be necessary because peak water demands can be supplied from storage. Storage also maintains the water supply during outages at the plant or at the source and it provides large amounts of water immediately for fire fighting purposes.

11. *HIGH SERVICE PUMPS*

    Unless the water system can be served entirely by gravity flow from a storage reservoir, high service pumps are required. The pumps draw water from storage and supply it to the system under pressure. Often one or more hydropneumatic pressure tanks are installed with the pumps.

Many small water treatment facilities are "package plants" (Figure 4.3) which can be purchased as a complete preassembled unit from a single manufacturer. Such package plants are available from a number of manufacturers. These units are most commonly supplied for filtration of turbid waters and for removal of dissolved iron and manganese. Usually the package plant includes all the treatment equipment, pumps, chemical feeders and controls. As soon as the water pipes and the electric power have been connected, the plant is ready to operate. Thus the package plant is frequently a quick way to provide the needed treatment. Another advantage of the package plant is that the design and the equipment have been proven effective and reliable by experience. All the "bugs" have been eliminated and the purchaser can usually have a high degree of confidence in the performance of the plant.

When operating a package plant, beware of claims that the plant operates "automatically." Even automatic systems require maintenance, repairs and occasional process control changes. These plants may be easily upset by sudden changes in source water quality.

---

[1] *Wye Strainer. A screen shaped like the letter Y. The water flows in at the top of the Y and the debris in the water is removed in the top part of the Y.*

[2] *Trihalomethanes (tri-HAL-o-METH-hanes). Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.*

[3] *Coagulation (co-AGG-you-LAY-shun). The clumping together of very fine particulates into larger particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.*

[4] *Clear Well. A reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand. Also used to provide chlorine contact time for disinfection.*

The alternative to a purchased package plant is a custom-designed plant which is assembled from equipment and materials supplied by several different manufacturers. This approach is sometimes less expensive than a package plant but the effectiveness of the resulting treatment plant is less predictable and may be unsatisfactory. The success of the plant depends on the ability of the person who designs the equipment and the skill and knowledge of the operator.

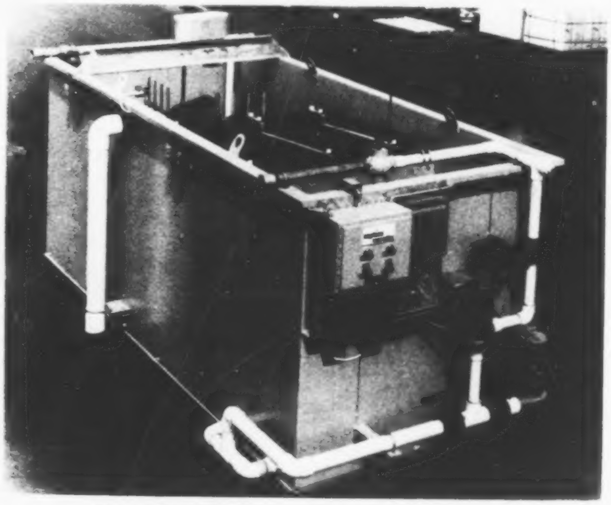


Fig. 4.3 Package water treatment plant

(Permission of Neptune Microfloc)

4.02 Groundwaters

Many small communities obtain their drinking water from wells. Sometimes the only additional treatment needed is the application of chlorine for disinfection. Other well waters may require treatment to remove iron and manganese or softening to remove excess hardness. In this chapter we will discuss the control of iron and manganese and also hardness at small water treatment plants. The application of chlorine for disinfection follows similar procedures when treating either surface or groundwaters.

1. *IRON AND MANGANESE CONTROL*

   Iron in drinking water can be controlled by converting iron from the liquid ferrous (Fe^{2+}) to the solid ferric (Fe^{3+}) form by the *OXIDATION*[5] process. First an oxidizing agent such as chlorine or potassium permanganate is used. Next oxygen is introduced to the water by the use of sprays, cascades or trays. Finally an hour or so (depending on the chemical make-up of the water) is allowed for the oxidation reaction to be completed and the insoluble *PRECIPITATES*[6] of iron and manganese are formed. The precipitates are removed by sedimentation and filtration or by filtration alone. Sometimes manganese is controlled by the addition of polyphosphates followed by chlorination.

Re-A-gent
Pre-SIP-i-TATE

2. *SOFTENING*

   Hardness in water is caused mainly by the presence of calcium and magnesium. Excessive hardness is undesirable to domestic consumers due to difficulties in doing the laundry and washing dishes. Water is softened by either the ion exchange process or by chemical precipitation (lime-soda ash softening). Softened water delivered to consumers usually has a hardness level of around 80 to 90 mg/*L* expressed as *CALCIUM CARBONATE EQUIVALENT.*[7]

4.03 Operator Responsibility

Operators of small water treatment plants probably have the toughest job of anyone in the waterworks field. In many small plants they have to do all of the work all by themselves. They have full responsibility to produce and deliver a pleasant and potable water. There is no one else to share the responsibility with them. Often these operators receive fairly low pay, support from others is minimal, there never is enough of the right kinds of tools, money for maintenance and repairs is always of concern, and nobody appreciates how hard the operator works. If you are in this position, you can do a good job if you use a lot of imagination and initiative. We hope this manual will provide you with the information to convince your supervisors and consumers that you need more help to do your job.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 218.

4.0A Why is a water supply that needs no treatment very rare?

4.0B How does the storage of raw water in lakes, ponds or reservoirs help the water treatment plant operator?

4.0C What information does an operator obtain from a flow meter?

4.0D How can a flow meter be protected?

4.0E Groundwaters may require what types of treatment?

---

[5] *Oxidation (ox-uh-DAY-shun). Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.*

[6] *Precipitate (pre-SIP-uh-TATE). To separate (a substance) out in solid form from a solution, as by the use of a reagent. The substance precipitated.*

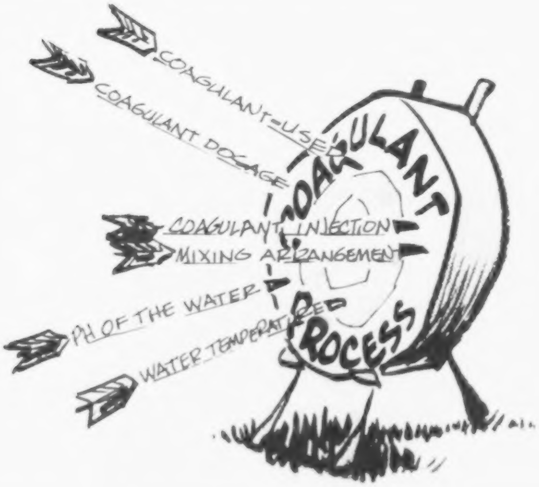
Reagent (re-A-gent). A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

[7] *Calcium Carbonate ($CaCO_3$) Equivalent. An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.*

4.1 COAGULATION

Coagulation is the chemical reaction that occurs when a coagulating chemical is added to water. The most common coagulating chemical used is aluminum sulfate (alum) but other chemicals are sometimes used. When one of these coagulants is added to water, it reacts directly with the water and with certain minerals dissolved in the water to form floc particles. These are small jelly-like, filmy particles that look like snowflakes.

The coagulant also reacts physically with the fine particles of suspended matter in the water. These particles, which cause the water to appear turbid or cloudy, normally have a negative electrical charge on their surface. This charge causes the particles to repel one another and remain suspended in the water rather than clumping together and settling to the bottom. The effect of the coagulant is to neutralize the negative charge on the suspended particles (destabilize the particles) so they can be brought together into larger clumps that are heavy enough to settle.



Many factors affect the coagulation process. Among the most important are the coagulant used, the coagulant dosage, the pH of the water, the mineral content of the water, the water temperature and the coagulant injection-mixing arrangement. Under any given set of conditions a particular water requires a certain optimum dosage of coagulant for coagulation to be successful. If the coagulant dosage is either too high or too low, coagulation will be incomplete and the results of treatment will be unsatisfactory. The pH of the water must be controlled within a narrow range during coagulation to achieve optimum results. The water must have an adequate *ALKALINITY*[8] content to achieve good coagulation with alum. The treatment is even more effective if the water contains abundant amounts of certain minerals, such as calcium and magnesium. Other chemicals (phosphate compounds for example), inhibit coagulation and require larger dosages of coagulant. Any chemical reaction proceeds faster when the water is warm than when it is cold and the method of injecting the coagulant and mixing it with the water has a very significant effect on the results of coagulation treatment. For effective treatment, the chemical must be completely mixed throughout the water being treated.

All these variables make it impossible to calculate what dosage of coagulant will produce the best results under a given set of conditions. Thus, in even the largest water treatment plant, the coagulant dosage must be estimated by performing a *JAR TEST.*[9] A jar test is a laboratory procedure in which varying dosages of coagulant are tested in a series of glass or plastic jars under identical conditions. A jar test apparatus like the one shown in Figure 4.4 is required for the test. The machine consists of a set of six paddle mixers (gang stirrer) all driven by a variable-speed motor. A jar containing the water to be treated is placed under each paddle mixer and varying dosages of coagulant are added to the jars. If the optimum dosage is suspected to be about twenty milligrams per liter of alum, that dosage plus both higher and lower dosages would be tested for comparison. For instance, the following dosages might be tested in one jar test series.

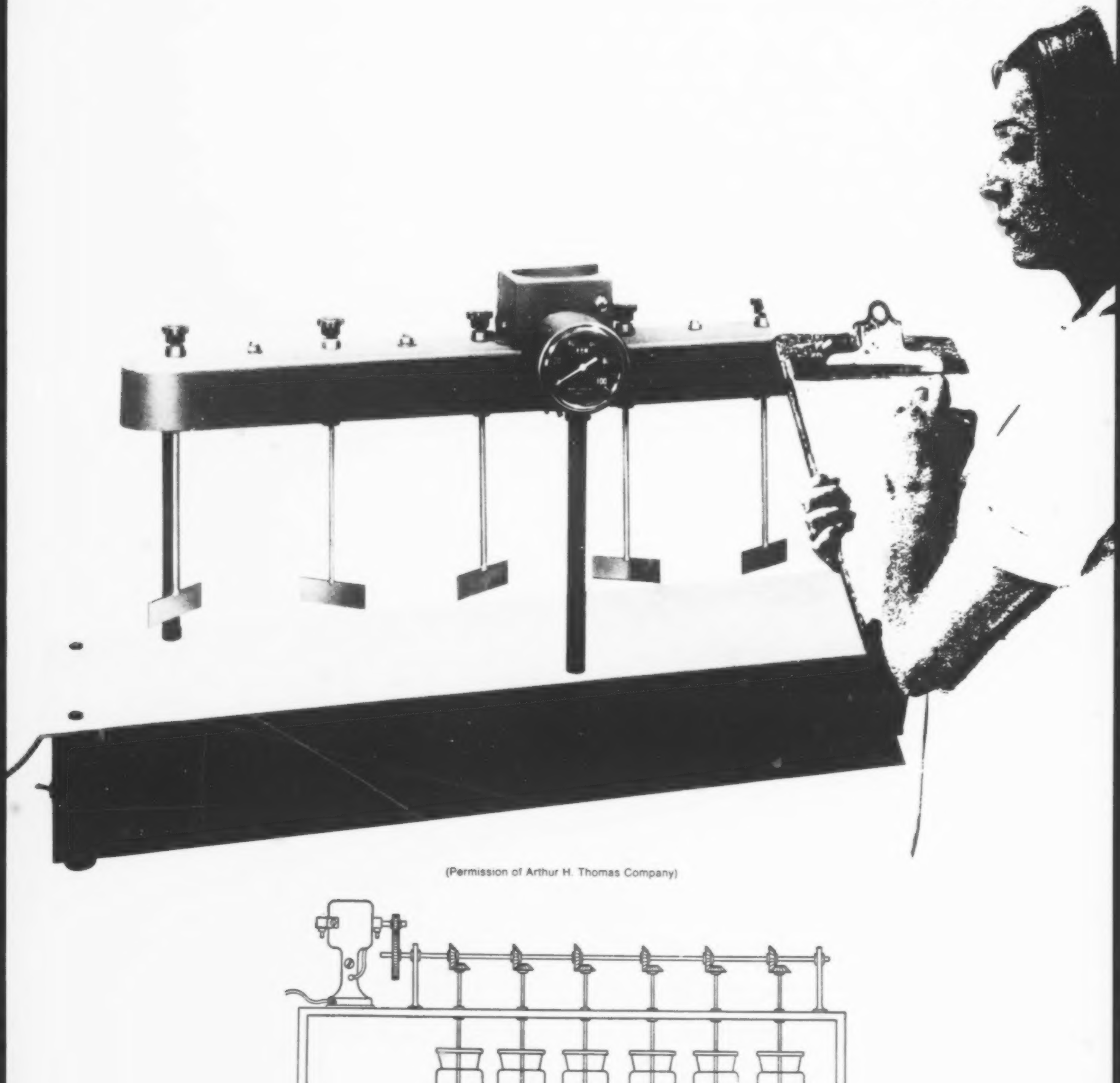
Jar Number	Alum Dosage, mg/*L*
1	14
2	16
3	18
4	20
5	22
6	24

After the proper coagulant dosage is added to each jar, the paddles are run at high speed for a short time to simulate rapid mixing. Then the paddles are adjusted to a very low speed for a longer period of time to simulate conditions in the flocculation basin of the plant. After a period of time, the paddles are stopped and all jars are observed to evaluate the settling results. The evaluation can be made by simple visual observations or by performing further laboratory tests. Ordinarily, the operator will visually observe which coagulant dosage produces the first visible floc, which dosage produces the largest, strongest floc, or which dosage produces the floc that settles the fastest. On this basis the operator can often select the optimum dosage to use in the plant. Other laboratory tests that are sometimes used to evaluate a jar test are (1) the pH of the water, (2) the turbidity of the settled water, and (3) the filterability of the water as determined by filtration through some type of small laboratory filter.

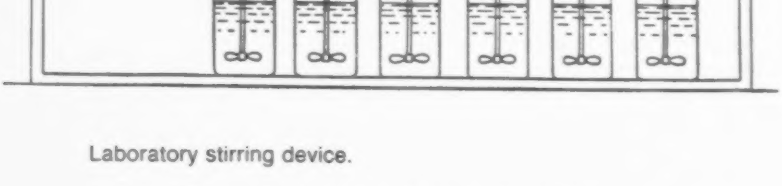
---

[8] *Alkalinity (AL-ka-LIN-ity). The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.*

[9] *Jar Test. See Chapter 11, "Laboratory Procedures," in this manual for additional details on how to perform the Jar Test.*



(Permission of Arthur H. Thomas Company)



Laboratory stirring device.

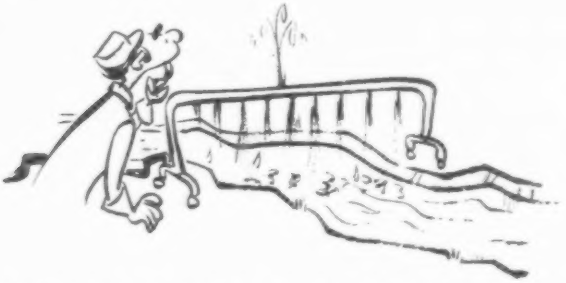
(Reprinted from *HANDBOOK OF APPLIED HYDRAULICS*, by permission. Copyright 1952, McGraw-Hill Book Company.

Fig. 4.4 Jar test apparatus

If the characteristics of the source water change rapidly because of storm conditions or other causes, jar tests may have to be conducted very frequently. At other times when the raw water quality is nearly the same from day to day, a jar test may be necessary only on occasion to verify the dosage. Some operators measure the turbidity of the source water and perform the jar test to determine the optimum coagulant dosage. By keeping accurate records they can develop a plot of turbidity vs. dosage. Whenever the turbidity changes, they have a good idea of the optimum dosage.

If you do not have a jar test apparatus, collect a water sample in a glass jar directly from the outlet of the rapid mix chamber in the plant. By gently hand stirring the water sample for a few minutes, you can sometimes get an idea of how well the water is coagulating. This method is crude but it is better than doing nothing to monitor coagulation.

Some operators will collect samples from the outlet of the rapid mix chamber and use this water for a jar test. They will add additional doses of coagulant to two jars and dilute a couple of the jars with raw water. Observing the results can indicate whether the dosage should be increased or decreased.



The manner in which the coagulant is injected into the water is very important. The coagulant should be brought into contact with every portion of water and completely mixed with it as fast as possible. Therefore the injection facilities and mixing equipment must be designed to produce good mixing. Mixing must be very rapid and turbulent because the coagulation reactions occur quickly, probably in the first few seconds and certainly within one minute. Experience has shown repeatedly that the optimum injection-rapid mix arrangement can greatly improve the results of coagulation and at the same time significantly decrease the amount of coagulant chemical that is used.

The best type of injector is usually one with multiple-feed orifices that will uniformly distribute the chemical solution throughout the flow of water. Thus a perforated pipe that extends completely across the width of the channel or the diameter of the pipeline is a better injector than one that injects at a single point. Also, locating the injector at a point of turbulent flow, such as a *PARSHALL FLUME,*[10] provides better mixing than locating the injector in an area of smooth, quiet flow. Thorough distribution of the chemical in combination with violent mixing is the most desirable arrangement.

If coagulation is not properly done, the treatment processes that follow (*FLOCCULATION,*[11] settling, and filtration) will be much less effective in purifying the water. Suspended matter will pass through the filters because of poor coagulation and the treated water will be cloudy and turbid. Dissolved alum may also pass through the filters and coagulate later in the clear well reservoir or in distribution system pipelines causing customer complaints about particles in the water and a dirty tasting water. Thus, if alum floc appears in the treated water or if alum is present in the treated water in concentrations greater than 0.1 mg/*L*, the operator should review the coagulation treatment for proper operation.

If you suspect that the coagulation treatment is substandard or if excessive dosages of coagulant are required, check the items listed below.

1. Perform a series of jar test experiments to simulate conditions in the treatment plant and determine the optimum coagulant dosage needed for the prevailing water quality conditions. Remember, the jar test is an indication of what's happening in your plant. *YOU MUST OBSERVE* the actual coagulation, flocculation and settling in your plant in order to determine the optimum chemical dosage.

2. Measure the pH of the water after the coagulant is added. Is the pH the same that normally prevails when good coagulation occurs? A record of daily pH readings is very helpful in determining the optimum pH for coagulation under different conditions. Sometimes jar tests are run at different pH levels to find the optimum pH.
3. Measure the alkalinity. Is adequate alkalinity present for the coagulation reaction to occur? If not, consider increasing the alkalinity to have at least thirty mg/*L* remaining when the chemical reactions are complete by adding sufficient lime or soda ash prior to coagulation.
4. Is the chemical feeder supplying the correct dosage of coagulant? The feeder may be broken or plugged up. Also, the feeder may be incorrectly adjusted. Measure the amount of chemical actually being fed and calculate the dosage. See Examples 1 and 2 on page 173. If the coagulant chemical is fed in the dry form, the operator can simply weigh the amount of coagulant that the feeder supplies in a certain period of time, say three minutes. A sensitive laboratory scale is needed to weigh the chemical accurately. If the coagulant chemical is fed in a water solution, the simple measuring device illustrated in Figure 4.5 can be used to measure the volume of solution supplied by the feeder pump in a given time. See Examples 3 and 4.

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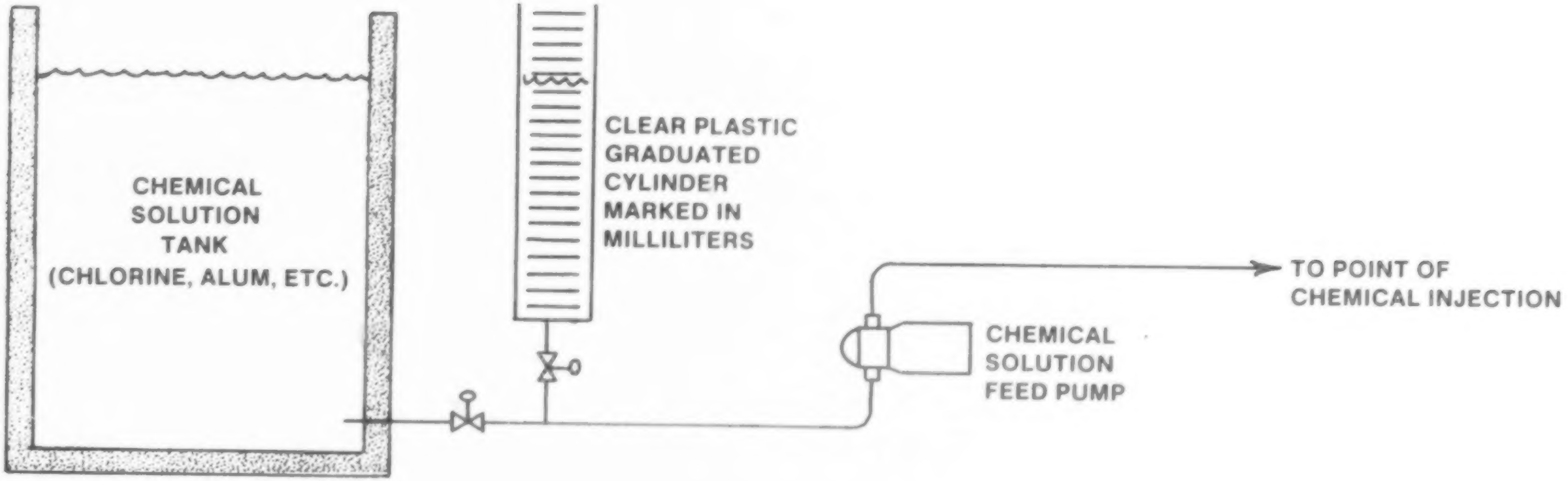
[10] *Parshall Flume. A device used to measure the flow in an open channel. The flow narrows to a throat of fixed dimensions and then expands again. The rate of flow can be calculated by measuring the difference in head (pressure) before and at the throat of the flume.*

[11] *Flocculation (FLOCK-you-LAY-shun). The gathering together of fine particles to form larger particles by a process of gentle mixing.*


CHEMICAL SOLUTION TANK (CHLORINE, ALUM, ETC.)
CLEAR PLASTIC GRADUATED CYLINDER MARKED IN MILLILITERS
TO POINT OF CHEMICAL INJECTION
CHEMICAL SOLUTION FEED PUMP

THE FEED RATE OF A CHEMICAL SOLUTION FEED PUMP CAN BE DETERMINED BY MEASURING THE AMOUNT OF SOLUTION WITHDRAWN FROM A GRADUATED CYLINDER IN A GIVEN TIME PERIOD. ALLOW THE CYLINDER TO FILL WITH SOLUTION. THEN CLOSE THE VALVE ON THE LINE FROM THE TANK SO THE FEED PUMP TAKES SUCTION FROM THE CYLINDER ONLY. OBSERVE THE MILLILITERS OF SOLUTION USED IN ONE MINUTE. COMPARE THIS RESULT WITH THE DESIRED FEED RATE AND ADJUST THE FEED PUMP ACCORDINGLY.

Fig. 4.5 Calibration of a chemical feed pump

5. Does the chemical feeder inject a steady feed of chemical into the water? If the feeder injects in "pulses" or "slugs," are the "pulses" as frequent as possible? If the feeder injects a "slug" only at rather long intervals, the chemical is not being uniformly distributed throughout the water. This can be corrected by diluting the chemical solution and readjusting the feeder pump to "pulse" more frequently.

6. Is the chemical injector distributing the coagulant completely throughout the flow of water? Injectors with multiple-feed orifices are better than those with a single-feed orifice.

7. Is violent rapid mixing provided just after the chemical is injected into the water? If not, the operator can install a mechanical mixer or relocate the point of injection to a zone of turbulent flow such as a Parshall flume, a pump intake, or an in-line static mixer.

8. Consider use of a coagulant aid such as an organic *POLYMER*.[12]

9. Examine the source water for a change in quality due to pollution, storm water runoff, use of a different water source or other causes.

10. Modify conditions at the intake or diversion to provide a water of more uniform quality to the plant. If large temporary changes occur frequently in the source water (during a storm), if possible turn off the plant and wait until water quality conditions are more stable and uniform.

11. Investigate the suitability of other coagulants. Pure aluminum sulfate is a cheaper and more effective coagulant than potassium alum or ammonium alum. These chemicals can be easily confused by suppliers and operators who are not aware of their differences.

For additional information on coagulation, See Chapter 4, "Coagulation and Flocculation," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals.

FORMULAS

In order to determine the *ACTUAL* feed rate of a dry chemical feeder:

1. Weigh a pan,
2. Place the pan under the feeder and then weigh the pan and chemicals,
3. Record the time the pan collected the chemical, and
4. Calculate the actual chemical feed or dose in pounds per day.

$$\text{Actual Chemical Feed, lbs/day} = \frac{(\text{Weight of Chemical, lbs})(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Chemical Collected, min})}$$

$$\text{Weight of Chemical, lbs} = \frac{(\text{Weight, grams})}{454\text{ grams/lb}}$$

(Use this formula only if scale weighs in grams.)

In order to determine the *DESIRED* feed rate from a dry chemical feeder:

1. Measure and record the flow of water being treated. If the flow is in gallons per minute (GPM), convert the flow to million gallons per day (MGD).
2. Determine the desired dose in mg/*L* using the jar test.
3. Calculate the desired feed rate in pounds per day.

$$\text{Desired Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$\text{Flow, MGD} = \frac{(\text{Flow, gal/min})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

In Figure 4.5, the chemical solution tank contains a hypochlorite solution containing 0.1 pounds of chlorine per gallon of solution or the solution may be given as a percent. The clear plastic graduated cylinder is filled with the hypochlorite solution. In order to determine the actual feed rate of the chemical solution feed pump in pounds per day:

1. Pump a portion of the chemical solution from the graduated cylinder and record the volume pumped in milliliters.
2. Determine the time required to pump the volume in milliliters.
3. Calculate the concentration of the chemical solution in either milligrams per liter or milligrams per milliliter.

$$\text{Chemical Con., mg/}L = \frac{(\text{Chem. Conc., lbs/gal})(1{,}000{,}000)}{(8.34\text{ lbs/gal})(1\text{ Million})}$$

or

$$\text{Chemical Conc., mg/}L = (\text{Chemical Conc., \%})(10{,}000\text{ mg/}L/\%)$$

$$\text{Chem. Feed, lbs/day} = \frac{(\text{Chem. Conc., mg/}L)(\text{Vol. Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$\text{Actual Dose, mg/}L = \frac{\text{Chemical Feed, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

---

[12] *Polymer. A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.*

EXAMPLE 1

A pan is placed under a dry alum feeder for exactly three minutes. The pan and alum are weighed. The alum weighed 45.4 grams. What is the actual alum feed in pounds per day?

Known		Unknown
Time, min	=3 min	Actual Alum Feed, lbs/day
Alum Weight, gm	=45.4 gm	

1. Convert alum weight from grams to pounds.

$$\text{Alum Weight, lbs} = \frac{\text{Weight, gm}}{454 \text{ gm/lb}}$$

$$= \frac{45.4 \text{ gm}}{454 \text{ gm/lb}}$$

$$= 0.1 \text{ lbs}$$

2. Calculate the actual alum feed rate in pounds per day.

$$\text{Actual Alum Feed, lbs/day} = \frac{(\text{Alum Weight, lbs})(60 \text{ min/hr})(24 \text{ hr/day})}{\text{Time Alum Collected, min}}$$

$$= \frac{(0.1 \text{ lbs})(60 \text{ min/hr})(24 \text{ hr/day})}{3 \text{ min}}$$

$$= 48 \text{ lbs/day}$$

EXAMPLE 2

Jar tests indicate that a water should be dosed with alum at 20 mg/*L*. The flow being treated is 200 GPM. What is the desired alum feed in pounds per day:

Known		Unknown
Alum Dose, mg/*L*	=20 mg/*L*	Desired Alum Feed, lbs/day
Flow, GPM	=200 GPM	

1. Convert the flow from gallons per minute (GPM) to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{(\text{Flow, gal/min})(1 \text{ Million})(60 \text{ min/hr})(24 \text{ hr/day})}{1{,}000{,}000}$$

$$= \frac{(200 \text{ gal/min})(1 \text{ Million})(60 \text{ min/hr})(24 \text{ hr/day})}{1{,}000{,}000}$$

$$= 0.288 \text{ MGD}$$

2. Calculate the desired alum feed rate in pounds per day.

$$\text{Desired Alum Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})$$

$$= (0.288 \text{ MGD})(20 \text{ mg}/L)(8.34 \text{ lbs/gal})$$

$$= 48 \text{ lbs/day}$$

NOTES

1. The actual alum feed in EXAMPLE 1 of 48 lbs alum per day agrees with the desired alum feed in EXAMPLE 2 of 48 lbs alum per day. If the actual feed does not agree with the desired feed, then the actual feed rate should be adjusted.
2. Remember that actual performance is what counts. Jar tests are used to help you get close to the desired dose. Fine adjustments must be made on the basis of actual field tests and observations.

EXAMPLE 3

The chemical solution feed pump in Figure 4.5 removes 500 m*L* from the graduated cylinder in 4 minutes. The concentration of the hypochlorite solution is 0.1 pounds chlorine per gallon. Determine the chemical feed rate in pounds per day delivered by the pump.

Known		Unknown
Volume Pumped, m*L*	=500 m*L*	Chemical Feed, lbs/gal
Time Pumped, min	=4 min	
Chem. Conc., lbs/gal	=0.1 lbs/gal	

1. Calculate the chemical concentration in the graduated cylinder in milligrams per liter.

$$\text{Chem. Conc., mg}/L = \frac{(\text{Chem. Conc., lbs/gal})(1{,}000{,}000)}{(8.34 \text{ lbs/gal})(1 \text{ Million})}$$

$$= \frac{(0.1 \text{ lbs/gal})(1{,}000{,}000)}{(8.34 \text{ lbs/gal})(1 \text{ Million})}$$

$$= \frac{12{,}000 \text{ lbs Chlorine}}{1 \text{ Million lbs Water}}$$

$$= 12{,}000 \text{ mg}/L$$

2. Determine the chemical feed rate of the pump in pounds of chlorine per day.

$$\text{Chem. Feed, lbs/day} = \frac{(\text{Chem. Conc., mg}/L)(\text{Vol. Pumped, m}L)(60 \text{ min/hr})(24 \text{ hr/day})}{(\text{Time Pumped, min})(1000 \text{ m}L/L)(1000 \text{ mg/gm})(454 \text{ gm/lb})}$$

$$= \frac{(12{,}000 \text{ mg}/L)(500 \text{ m}L)(60 \text{ min/hr})(24 \text{ hr/day})}{(4 \text{ min})(1000 \text{ m}L/L)(1000 \text{ mg/gm})(454 \text{ gm/lb})}$$

$$= 4.8 \text{ lbs/day}$$

NOTE: If the concentration of the hypochlorite solution in EXAMPLE 3 was given as a 1.2 percent solution, then

$$\text{Chem. Conc., mg}/L = (\text{Chemical Conc., \%})(10{,}000 \text{ mg}/L/\%)$$

$$= (1.2\%)(10{,}000 \text{ mg}/L/\%)$$

$$= 12{,}000 \text{ mg}/L$$

EXAMPLE 4

Calculate the actual chlorine dose in milligrams per liter in the water being treated in Example 3. The hypochlorinator (chemical feed pump) delivers 4.8 pounds of chlorine per day and the flow rate of the water being treated is 250,000 gallons per day (0.25 MGD).

Known		Unknown
Chemical Feed, lbs/day	=4.8 lbs/day	Actual Dose, mg/*L*
Flow, MGD	=0.25 MGD	

Calculate the actual chlorine dose in milligrams per liter.

$$\text{Actual Dose, mg}/L = \frac{(\text{Chemical Feed, lbs/day})}{(\text{Flow, MGD})(8.34 \text{ lbs/gal})}$$

$$= \frac{4.8 \text{ lbs/day}}{(0.25 \text{ MGD})(8.34 \text{ lbs/gal})}$$

$$= 2.3 \text{ mg}/L$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 218.

4.1A What is the influence of temperature on the coagulation process?

4.1B How are the results of jar tests evaluated?

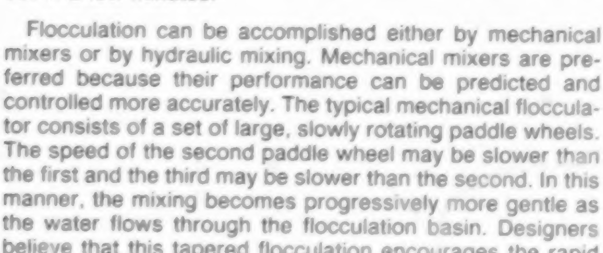
4.1C How can operators determine whether the coagulant dose should be increased or decreased?

4.1D How can the alkalinity of the water being treated be increased?

4.2 FLOCCULATION

Flocculation is a process of slow, gentle mixing of the water to encourage the tiny floc particles to clump together and grow to a size that will settle quickly. When the particles of floc first form they are too small to be visible to the naked eye. A floc particle of this size is also too small to settle in a reasonable time. Therefore, the process of flocculation or gentle mixing is used to bring the small particles of floc and other suspended matter into contact with each other so they will stick together and form larger particles. By the time the floc particles grow to a size of about 1/16 inch (1.5 mm) diameter or larger, they are usually heavy enough to settle out in a few minutes.

Flocculation can be accomplished either by mechanical mixers or by hydraulic mixing. Mechanical mixers are preferred because their performance can be predicted and controlled more accurately. The typical mechanical flocculator consists of a set of large, slowly rotating paddle wheels. The speed of the second paddle wheel may be slower than the first and the third may be slower than the second. In this manner, the mixing becomes progressively more gentle as the water flows through the flocculation basin. Designers believe that this tapered flocculation encourages the rapid growth of larger floc particles.



Other types of mechanical flocculators exist but the purpose of all flocculators is to provide gentle mixing that will produce a quick settling floc. The mixing must be strong enough to prevent premature settling of floc in the flocculation basin, but the mixing must not be so strong that it breaks apart the floc particles already formed. Mechanical flocculators are preferred because their operation is flexible enough to maintain the proper mixing regardless of the rate of flow through the plant and because the degree of agitation can be adjusted to suit changes in water quality.

Flocculation is sometimes attempted by means of hydraulic mixing. Hydraulic mixing occurs when water flows around obstructions or obstacles such as a series of baffles or through a series of interconnected chambers. Around-the-end baffles are commonly used to create back and forth flow through a basin. Over and under baffles are used to create an up and down rolling motion to the flow of water. Other hydraulic devices such as orifices, weirs, or vortex chambers may also be used to create hydraulic mixing.

Most hydraulic flocculators suffer from serious drawbacks. Mixing is less uniform and controllable, being too violent in one spot and too gentle in another. While hydraulic flocculators may perform well at one rate of flow, they usually give poor results at flows greater or less than that for which they are designed. Thus they have less flexibility of operation than mechanical flocculators because the degree of mixing depends on the flow rate.

The success of flocculation is affected by only a few factors. The primary factor is the degree of mixing. If mixing is too gentle, the suspended particles will not be brought into contact with one another and there will be fewer opportunities for large clumps of floc to form. Conversely, mixing that is too violent will tear apart the floc particles and prevent them from attaining proper size. The time of mixing is also important to proper flocculation. A minimum time of mixing is necessary for flocculation to be completed. Usually a period of thirty to forty five minutes is sufficient. To insure that all portions of the water are retained in the flocculator for the required time, it is important to limit *SHORT-CIRCUITING.*[13] This can usually be accomplished by proper baffling or by providing several compartments in series (one after another). Three or more compartments in series is recommended. A third factor affecting flocculation is the number of particles. A relatively clear water is harder to flocculate than a turbid water containing a lot of suspended matter. The difference is that the greater number of particles in the turbid water collide with one another more often.

If flocculation is not satisfactory in producing a floc that settles quickly and clarifies the water effectively, take the following corrective steps.

1. Correct any deficiencies in the coagulation process.
2. Check the degree of mixing. Be sure the mixing is neither too gentle nor too violent.
3. Make sure that mixing is provided for an adequate time period. The flow rate through the floc basin may be too high. Are actual flows greater than design flows?
4. See that short-circuiting of flow through the basin is prevented so each portion of the water is retained as long as possible.

---

[13] *Short-circuiting. A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.*

5. Adjust the plant to operate on a more continuous basis for longer periods of time. Frequent on-off operation is harmful to flocculation because the floc settles to the bottom when the plant is off and must be resuspended when it starts again. When adjusting flows, consider previous flows, expected demands and available storage.

For additional information on flocculation, see Chapter 4, "Coagulation and Flocculation," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 218.

4.2A What is flocculation?

4.2B What happens if the flocculation mixing is too strong or too weak?

4.3 SETTLING (SEDIMENTATION)

Settling or sedimentation is the process of holding the water in quiet, low flow conditions so suspended matter and particles can be settled out by gravity to the bottom of the tank and removed as sludge.

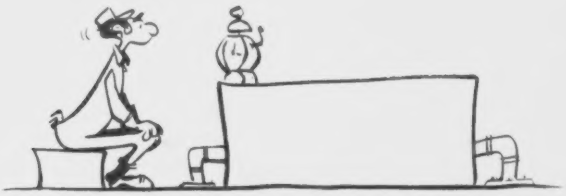
The purpose of settling is to remove as much of the floc and other suspended material as possible before the water flows to the filters. Settling is thus the final step of pretreatment prior to filtration. Settling is an economical means of clarifying water. Therefore it is usually practiced whenever the water contains even a moderate amount of suspended matter. Settling may be omitted sometimes when the water contains only a small amount of suspended matter, but settling is required when a lot of suspended matter is present.

To understand the operation of a settling tank, it is helpful to think of it as having four zones. These zones are shown in Figure 4.6. The size of each zone varies and the boundaries between the zones are vague and indefinite rather than sharp and well defined.

In the inlet zone, water entering the tank is distributed across the cross section of the tank and slows to a uniform flow velocity. Next, the water flows into the settling zone which is the main part of the tank. Here the water flows slowly through the tank and the suspended particles settle out. The settled material accumulates in the sludge zone at the bottom of the tank. At the end of the tank, the water enters the outlet zone where it flows to the outlet, collects in suitable channels and leaves the tank.

As the water flows through these zones in the settling tank, various factors have an important effect on the settling of suspended particles. Some of these factors are interrelated.

1. *THE TIME PROVIDED FOR SETTLING*



Commonly, a total settling time of two to four hours is provided. Related to the settling time is the flow velocity through the tank. The faster the water flows, the shorter time a particle has to settle out before the water reaches the outlet of the basin. The theoretical average flow velocity is usually limited to about one to three feet per minute (0.3 to 1 m/min). See Examples 5 and 6 on pages 177 and 178.

2. *THE CHARACTERISTICS OF THE SUSPENDED MATTER*

A dense particle of soil or sand will settle more quickly than a light floc particle. A dense, compact floc containing lots of suspended matter will settle quicker than a light, fluffy particle consisting only of alum floc. The coagulation and flocculation processes determine the settling characteristics of the floc.

3. *THE DEGREE OF SHORT-CIRCUITING THROUGH THE TANK*

Short-circuiting occurs when some portions of water pass through the settling tank faster than others. The amount of short-circuiting depends on the shape and dimensions of the tank. For this reason, a long narrow settling tank is more effective than a short, wide tank. Short-circuiting is also affected by the inlet and outlet arrangements of the tank.

4. *THE INLET AND OUTLET ARRANGEMENTS OF THE TANK*

The inlet arrangement should distribute the incoming water over the full cross section of the settling tank. The water should be distributed evenly both horizontally and vertically, and high velocities and eddy currents should be avoided. This is usually done by using perforated baffles or channels with multiple openings.

The outlet arrangement should allow the water leaving the tank to be collected near the surface, but uniformly across the width of the tank. The aim is to prevent high flow velocities that will lift already settled particles and carry them out of the tank. Long weir troughs are commonly used to collect the water as well as pipes with multiple ports submerged just below the surface.

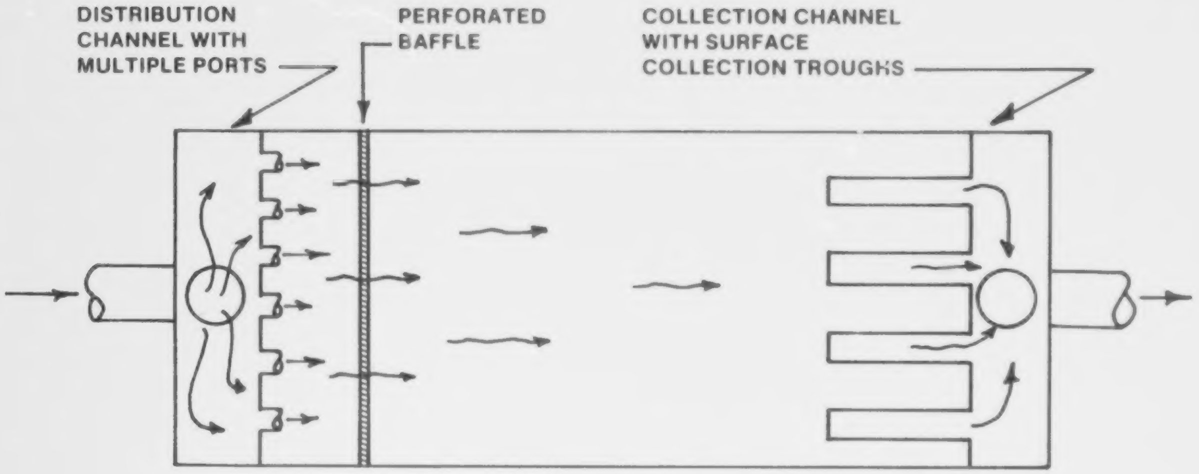
Relatively minor changes in the inlet or outlet arrangement in a settling tank can cause dramatic improvement in its settling efficiency.

5. *THE TANK OVERFLOW RATE*

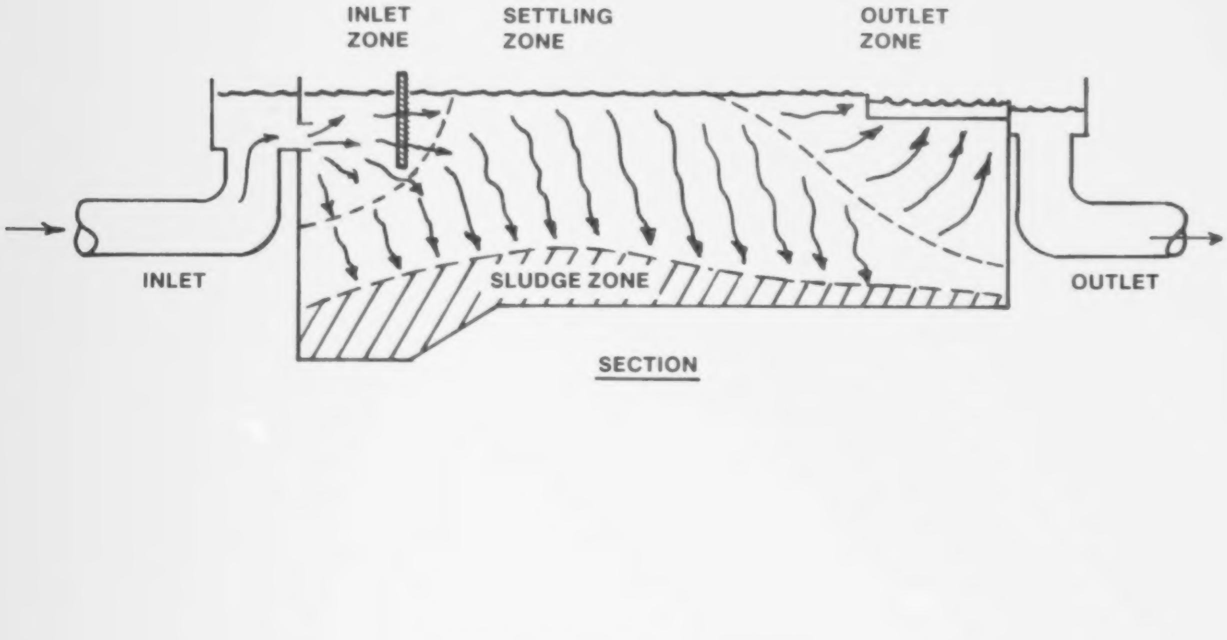
The tank overflow rate, sometimes called the surface loading rate, is determined by dividing the flow rate, Q, by the surface area of the tank. The overflow rate is normally expressed as gallons per day per square foot (GPD/sq ft or cu m/day/sq m). Typical values vary from 400 to 600 GPD/sq ft or 16 to 24 cu m/day/sq m. A lower rate is better than a higher one. See Example 6.

6. *THE CURRENTS IN THE TANK*

Currents caused by flow inertia, wind action, temperature differences and poor design can interfere with efficient settling, resuspend particles that have already settled and cause short-circuiting. The movement of mechanical sludge scrapers also causes currents that interfere with settling. Many small plants omit sludge scrapers to save costs.


DISTRIBUTION CHANNEL WITH MULTIPLE PORTS
PERFORATED BAFFLE
COLLECTION CHANNEL WITH SURFACE COLLECTION TROUGHS

PLAN


INLET ZONE
SETTLING ZONE
OUTLET ZONE
INLET
SLUDGE ZONE
OUTLET

SECTION

Fig. 4.6 Four zones of a settling tank

7. *THE TEMPERATURES OF THE WATER*

   Any particle settles faster in warm water than in cold water because warmer water is less viscous (like warm syrup) and offers less resistance.

8. *WIND*

   High winds can cause surface currents to develop and cause turbulence which will reduce settling.

The water leaving the settling tank should have a turbidity of less than five *TURBIDITY UNITS*[14] and not many floc particles should be carried out of the tank. If good settling is not being obtained, take the following actions to correct it.

1. Check the coagulation and flocculation processes to be sure they are operating as well as possible.
2. Decrease the rate of flow through the tank to lower the overflow rate and the velocity of flow, and to increase the time for settling to occur.
3. Improve inlet conditions to reduce inlet velocity, distribute the flow uniformly and create uniform flow velocities across the entire cross section of the tank. If more than one tank is used, make sure the flow is equally divided among the tanks as well.
4. Improve outlet conditions to eliminate excessive velocities toward the outlet. Install more weir troughs or outlet ports.
5. Remove accumulated sludge from the bottom of the settling tank.
6. Cover or screen the settling tank to diminish currents caused by changing wind and weather conditions.
7. Recycle sludge to the inlet of the settling tank to increase the number of particles in the water and improve flocculation of the settling particles.

High-rate or tube settlers were developed to increase the settling efficiency of conventional rectangular sedimentation basins. They have been installed in circular basins with successful results.

Water enters the inclined settler tubes and is directed upward through the tubes as shown in Figures 4.7, 4.8 and 4.9. Each tube functions as a shallow settling basin. Together, they provide a high ratio of effective settling surface area per unit volume of water. The settled particles can collect on the inside surfaces of the tubes or settle to the bottom of the sedimentation basin.

High-rate settlers are particularly useful for water treatment applications where site area is limited, in packaged-type water treatment units, and to increase the capacity of existing sedimentation basins. In existing rectangular and circular sedimentation basins, high-rate settler modules can be conveniently installed between the launders. High winds can have an adverse effect on tube settlers.

Water treatment plant sludges are typically alum sludges, with solids concentrations varying from 0.25 to 10 percent when removed from the basin. In gravity flow sludge removal systems, the solids concentration should be limited to 3 percent. If the sludge is to be pumped, solids concentrations as high as 10 percent can be transported.

In horizontal-flow sedimentation basins preceded by coagulation and flocculation, over 50 percent of the floc will settle out in the first third of the basin length. Operationally, this must be considered when establishing the frequency of operation of sludge removal equipment. Also you must consider the volume or amount of sludge to be removed and the sludge storage volume available in the basin.

Sludge may be discharged into sludge basins or ponds for liquid-solids separation. Ultimately the sludge may be disposed of in a landfill.

For additional information on settling, see Chapter 5, "Sedimentation," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals.

FORMULAS

To calculate the settling time or detention time in a basin:

1. Determine the basin dimensions and volume, and
2. Measure and record the flow of water being treated.

$$\text{Basin Volume, cu ft} = (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})$$

$$\text{Basin Volume, gal} = (\text{Basin Volume, cu ft})(7.48\ \text{gal/cu ft})$$

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

To calculate the basin overflow rate or surface loading:

1. Determine the basin length and width to determine the surface area, and
2. Measure and record the flow of water being treated.

$$\text{Surface Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$

$$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, gal/day}}{\text{Surface Area, sq ft}}$$

EXAMPLE 5

A rectangular settling basin 20-feet long, 10-feet wide and with water 5-feet deep treats a flow of 60,000 gallons per day. Estimate the detention time or settling time in hours for this basin when conveying this flow.

---

[14] *Turbidity Units. Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of the water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.*

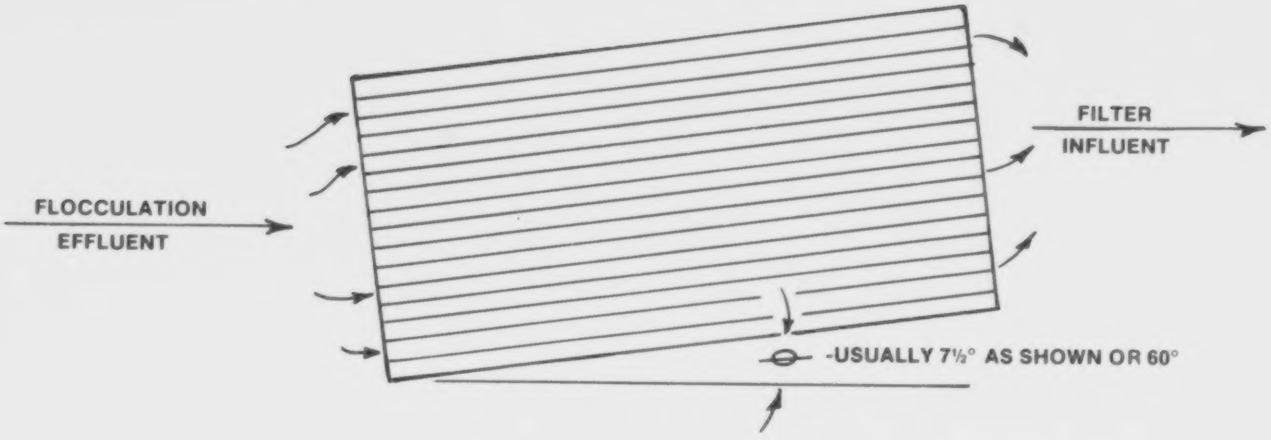
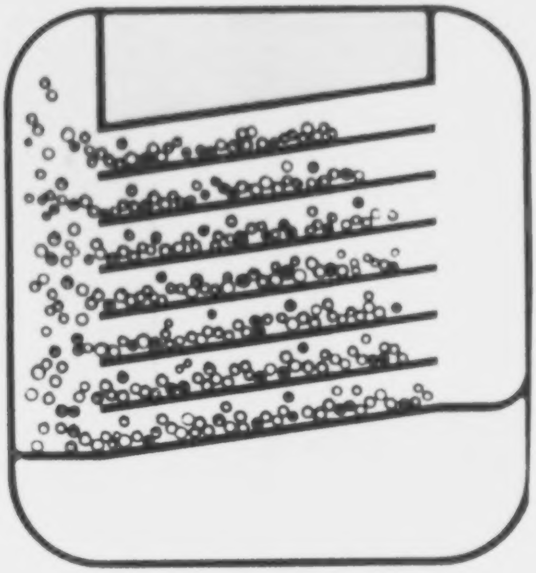
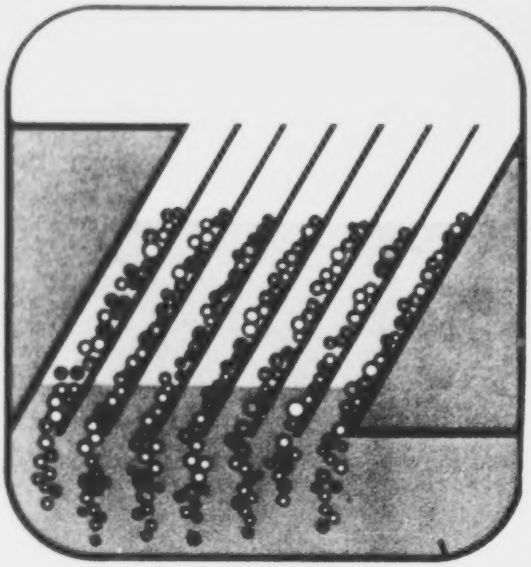

FLOCCULATION
EFFLUENT
FILTER
INFLUENT
-USUALLY 7½° AS SHOWN OR 60°

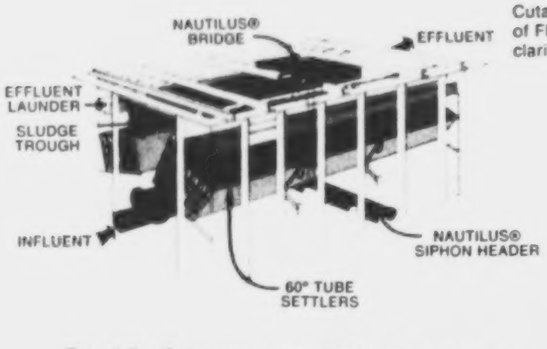
Fig. 4.7 Tube settler (installed in a rectangular or circular sedimentation basin)



7½° Tube Settlers



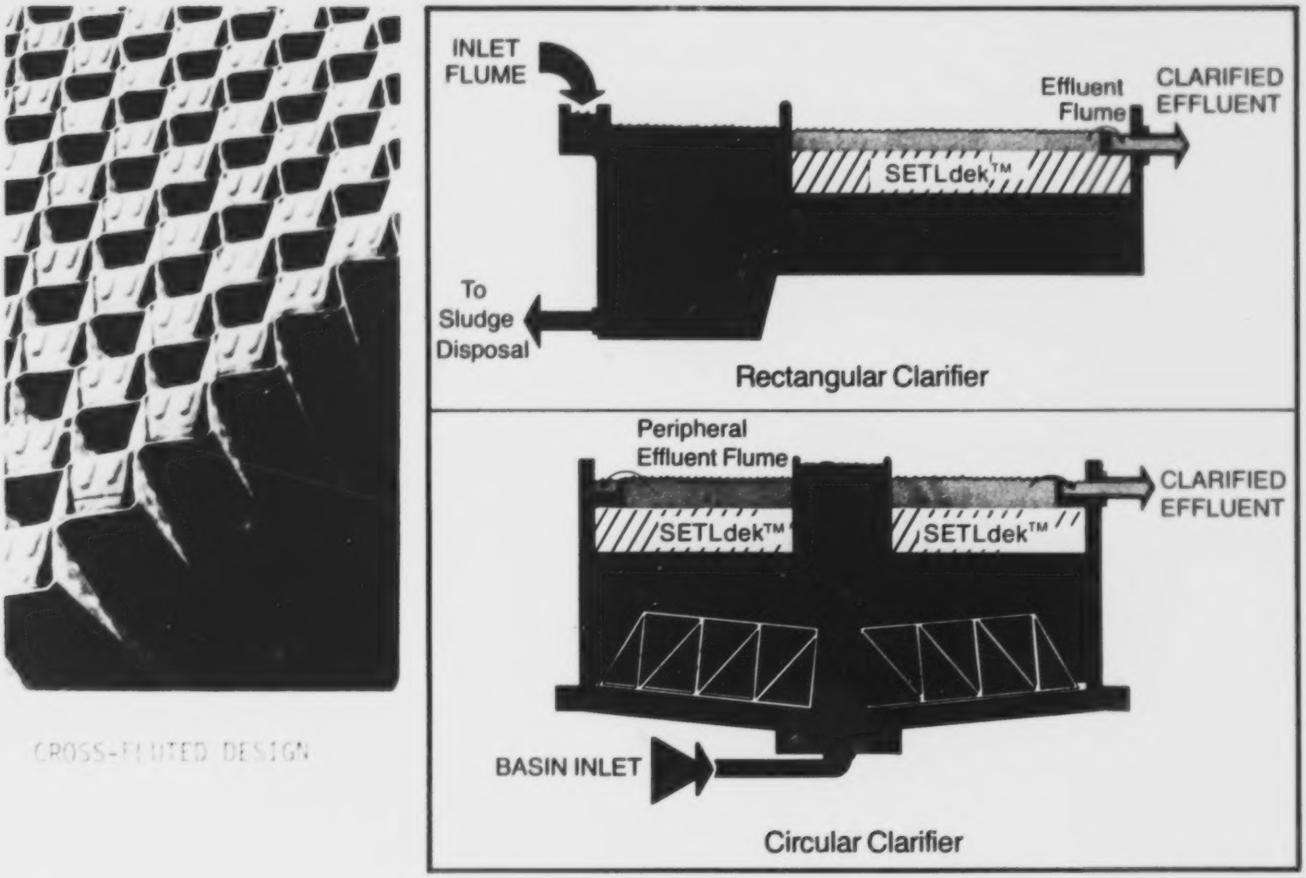
60° Tube Settlers


NAUTILUS®
BRIDGE
EFFLUENT
EFFLUENT
LAUNDER
SLUDGE
TROUGH
INFLUENT
NAUTILUS®
SIPHON HEADER
60° TUBE
SETTLERS

Cutaway view of Floc/Tube clarifier.

Fig. 4.8 Cutaway view of Floc/Tube clarifier

(Permission of Neptune Microfloc, Inc.)


INLET FLUME
Effluent Flume
CLARIFIED EFFLUENT
SETLdek™
To Sludge Disposal
Rectangular Clarifier
Peripheral Effluent Flume
CLARIFIED EFFLUENT
SETLdek™
SETLdek™
BASIN INLET
Circular Clarifier

CROSS-FLUTED DESIGN

Fig. 4.9 Tube settlers in rectangular and circular clarifiers

(Permission of The Munters Corporation)

Known		Unknown
Length, ft	=20 ft	Detention Time, hr
Width, ft	=10 ft	
Depth, ft	=5 ft	
Flow, GPD	=60,000 GPD	

1. Calculate the basin volume in gallons.

Basin Volume, cu ft =(Length, ft)(Width, ft)(Depth, ft)

=(20 ft)(10 ft)(5 ft)

=1000 cu ft

Basin Volume, gal =(Basin Volume, cu ft)(7.48 gal/cu ft)

=1000 cu ft)(7.48 gal/cu ft)

=7,480 gal

2. Calculate the detention time or settling time in hours.

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{(7{,}480\ \text{gal})(24\ \text{hr/day})}{60{,}000\ \text{gal/day}}$$

=3.0 hr

EXAMPLE 6

A rectangular settling basin 20-feet long, 10-feet wide, and 5-feet deep treats a flow of 60,000 gallons per day. Estimate the overflow rate of the basin in gallons per day per square foot of surface area.

Known		Unknown
Length, ft	=20 ft	Overflow Rate, GPD/sq ft
Width, ft	=10 ft	
Depth, ft	=5 ft	
Flow, GPD	=60,000 GPD	

1. Calculate the surface area in square feet.

Surface Area, sq ft =(Length, ft)(Width, ft)

=(20 ft)(10 ft)

=200 sq ft

2. Determine the basin overflow rate in gallons per day per square foot.

$$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, gal/day}}{\text{Surface Area, sq ft}}$$

$$= \frac{60{,}000\ \text{gal/day}}{200\ \text{sq ft}}$$

=300 GPD/sq ft

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 218.

4.3A What is the purpose of settling?

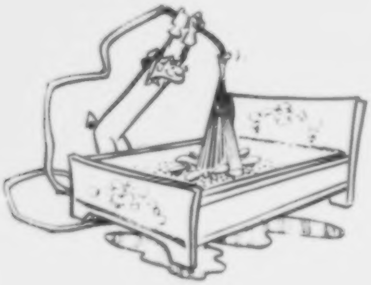
4.3B Short-circuiting is influenced by what factors?

4.3C How does temperature influence particle settling?

4.3D Why is sludge recycled to the inlet of the settling tank?

4.4 FILTRATION

Filtration is the process of passing water through a porous bed of fine granular material. The bed is usually 18 to 30 inches thick (45 to 75 cm).



The purpose of filtration is to remove suspended matter from the water. The suspended matter is mainly particles of floc, soil, and trash; but it also includes living organisms like algae, bacteria, virus and protozoa.

CHEMICAL COAGULATION IS ABSOLUTELY ESSENTIAL FOR EFFECTIVE FILTRATION. Filters using a granular filter media will not effectively remove fine suspended matter unless coagulation treatment is provided. Without coagulation, the filter will operate only as a strainer which removes the large coarse particles while the fine particles of suspended matter will easily flow right between the grains of filter media and pass through the filter without being removed. *ONLY PROPER COAGULATION CAN MAKE A GRANULAR MEDIA FILTER PERFORM EFFECTIVELY TO CLARIFY THE WATER.*

There are generally two types of filters used in water treatment. Both the gravity and pressure types are common. The open gravity filter type is shown in Figure 4.10. This filter is simply a tank with an open top which contains the water, the filtering media and other filter equipment. Water enters the filter near the top and flows downward through the filtering media under the force of gravity. Hence the name "gravity filter." At the bottom, the filtered water is collected in the underdrain system and flows out of the filter to the filtered water reservoir.

The second common type of filter is the pressure filter (Figure 4.11). The pressure filter is completely enclosed in a water-tight tank and the water is forced through the filter under pressure created by a pump or other pressure source.

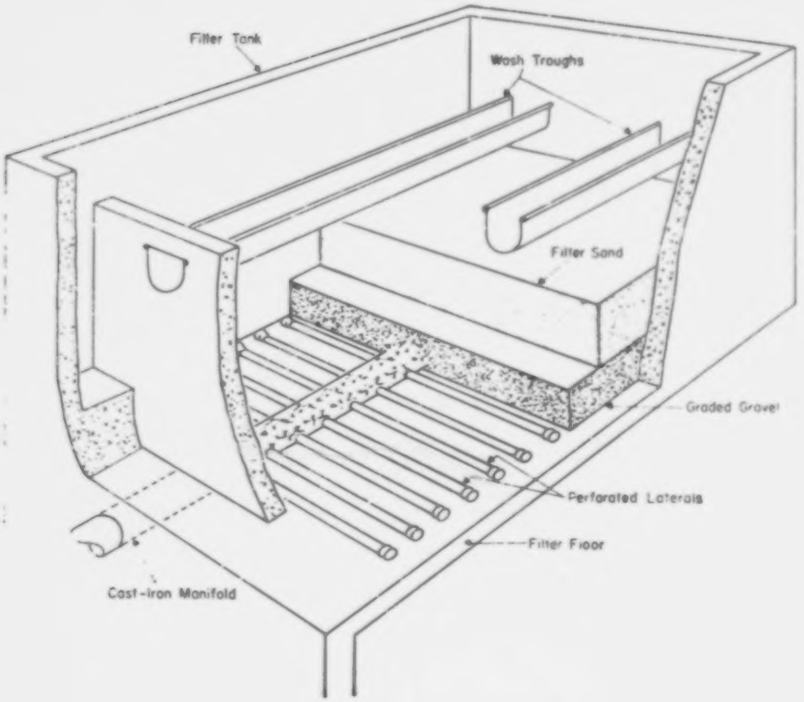


Fig. 4.10 Cutaway view of typical open gravity sand filter

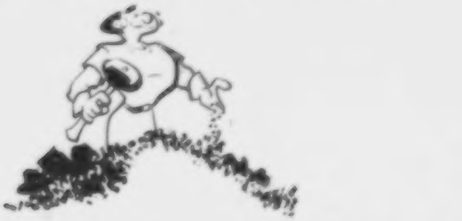
(Reprinted from *WATER TREATMENT PLANT DESIGN*, by permission.
Copyright 1969, the American Water Works Association.

When a bed of granular filtering media is used, the water enters the top of the filter tank and flows vertically downward as it does in a gravity filter. The underdrain system is also similar. However, some types of pressure filters use *DIATOMACEOUS EARTH*[15] (D.E.) temporarily deposited on fabric or wire screen elements to accomplish the filtering action. D.E. filters are common on swimming pools and large D.E. filters are sometimes used to filter domestic water supplies. Thus the interior arrangement of a pressure filter can vary considerably from one manufacturer to another.

Sand is the most frequently used filtering media for treatment of domestic water. The sand should be a hard material like quartz so it will not erode and crumble or easily dissolve in water. The depth of sand may vary from 20 to 30 inches (50 to 75 cm). A depth of 24 inches (60 cm) is common but some filters of special design may have only 6 to 12 inches (15 to 30 cm) of sand.

Raw sand from just any source is not suitable for filter media. This sand usually is not the right size and it is not properly "graded," that is, the different sizes are not present in the correct proportion. Therefore, filter sand must be prepared by screening the raw sand through a set of sieves and mixing the sand retained on each size sieve in the proper proportion. When this mixing operation is completed, the sand should consist of grains ranging in size from about 0.2 to 1.2 millimeters.

Anthracite is the second most frequently used filtering media. Anthracite is hard coal. Ordinarily anthracite is prepared by crushing the coal and sieving it to achieve the proper gradation. Properly graded anthracite will consist of grains ranging in size from about 0.5 to 3.0 millimeters.



Anthracite may be used as the only filtering media but it is more commonly used along with sand. When the two materials are used together, the filter is called a "dual media" filter. In the dual media filter, about 6 to 10 inches (15 to 25 cm) of sand is placed on the bottom and 18 to 24 inches (45 to 60 cm) of anthracite is placed on top. Since the sand is about two and a half times heavier than water and anthracite is only about one and a half times heavier than water, the two materials stay separated and in the same relative positions (anthracite on top and sand on the bottom) even after backwashing.

Sometimes a layer of crushed *GARNET*[16] media is used at the bottom of the filter in addition to the sand and anthracite. In this case, the filter is called a "mixed media" filter.

Small filters containing replaceable cartridge-type elements are sometimes used in homes or very small treatment plants. When the elements become plugged with dirt they

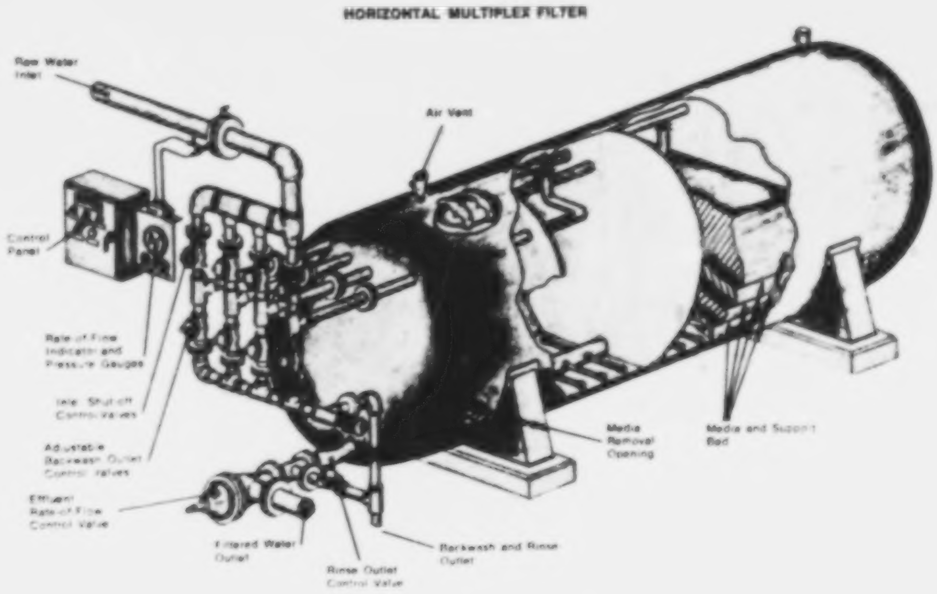

HORIZONTAL MULTIPLEX FILTER
Raw Water Inlet
Air Vent
Control Panel
Rate of Flow Indicator and Pressure Gauges
Inlet Shut-off Control Valves
Adjustable Backwash Outlet Control Valves
Effluent Rate-of-Flow Control Valve
Filtered Water Outlet
Rinse Outlet Control Valve
Backwash and Rinse Outlet
Media Removal Opening
Media and Support Bed

Fig. 4.11 Pressure filter

(Permission of Watermasters, Inc., Burlingame, California)

must be discarded and replaced since they cannot be cleaned and reused. The cost of replacement elements is often a significant expense.

---

[15] *Diatomaceous Earth (DYE-uh-toe-MAY-shus). A fine, siliceous (made of silica) "earth" composed mainly of the skeletal remains of diatoms.*

[16] *Garnet (GAR-nit). A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.*

The underdrain system of the filter is at the bottom beneath the filtering media. This system has several important functions:

1. To support the filtering media and prevent the media from passing out the bottom of the filter,
2. To collect the filtered water and convey this water out of the filter when the filter is in normal operation, and
3. To uniformly distribute the backwash water across the filter bed and provide uniform upward flow.

Of these three functions, the most important is uniform distribution of the backwash water.

The underdrain system usually consists of two parts, the gravel layers and the water conduits. The gravel layers, which are on top, usually consist of several layers of different size gravel. The uppermost layer of gravel, which is in contact with the sand, may be 1/16 to 1/8 inch (1.5 to 3 mm) in diameter and about three inches (75 mm) thick. There may be as many as six different layers of gravel, each larger in size than the one above. The bottom layer may be as large as 1½ to 2½ inches (35 to 65 mm) in diameter. The total depth of the gravel layers may vary from 12 to 24 inches (30 to 60 cm).

The bottom part of the underdrain system consists of the water conduits for collection of the filtered water and distribution of the backwash water. These conduits may consist of a large central header pipe with numerous small pipe laterals branching off the header. The header-lateral underdrain system is more common in older or smaller filters. Newer and larger filters most often use an underdrain system consisting of a false bottom constructed of porous stone plates or perforated hollow blocks of vitrified clay.

A rate-of-flow control valve orifice is normally placed in the effluent line from each filter. The purpose of this valve is to somewhat equalize the flow among all the filters and to prevent excessive rates of filtration by limiting the rate of flow through each filter to a predetermined value. The rate-of-flow controller also is used to maintain a constant flow through a given filter during the entire filter run. As the head loss through the filter builds up, the controller opens up to maintain a constant flow.

The rate of filtration, usually expressed in gallons per minute per square foot of filter area (GPM/sq ft), is an important characteristic of any filter. The slow sand filters built in the past operated at a filtration rate of about 0.05 GPM/sq ft (0.034 mm/sec or 0.034 liters per sec/sq m). When rapid sand filters were developed, they were usually designed to operate at a filtration rate of two GPM/sq ft (1.4 mm/sec or 1.4 liters per sec/sq m), approximately forty times faster. Modern filters using dual media and improved design can operate at rates ranging from three to five GPM/sq ft (2 to 3.4 mm/sec or 2 to 3.4 liters per sec/sq m). In a very few cases, filters have been designed and operated successfully at rates ranging from six to eight (4 to 5.4) or even as high as ten GPM/sq ft, (6.8 mm/sec or 6.8 liters per sec/sq m) but these filters are rare.

Successful operation of filters at high rates requires the following conditions:

1. Good design by a knowledgeable engineer or consultant,
2. Use of dual or mixed media,
3. Surface wash apparatus to assist cleaning of the media during backwash,
4. Use of polymers or other filter aids,
5. Turbidimeters which continuously monitor the performance of the filters,
6. Competent operators on duty continuously whenever the plant is operating, and
7. Excellent pre-treatment (coagulation, flocculation, and settling) to properly condition the water prior to filtration.

Since these conditions usually do not prevail in small water treatment plants, the rate of filtration should usually be restricted in small filters, or ones of poor design, to no more than about two GPM/sq ft (1.4 mm/sec or 1.4 liters per sec/sq m). See Example 7 on page 187.

As a filter operates, it continuously removes suspended matter from the water passing through it. Eventually this matter clogs the openings through the filter and the flow of water is reduced. Another sign of a dirty filter is "breakthrough" of excessive turbidity in the filtered water.

When a filter is operating properly, the head loss through the filter media will build up gradually (Figure 4.12). The actual head loss is measured by a filter head loss gage which is monitored by the operator. The head loss should never be as great as the distance from the water surface to the top of the filter media.

The rate of head loss build up is an important indicator of filter performance. Sudden increases in head loss might be an indication of surface sealing of the filter media (lack of depth penetration). Early detection of this condition may permit you to make appropriate process changes such as adjustment of the chemical filter-aid feed rate or adjustment of filtration rate.

When the filter becomes dirty (high head loss) it must be cleaned by backwashing. This is a process of reversing the direction of flow through the filter to flush the dirt out of the media. The backwash water enters the underdrain system at the bottom of the filter and flows upward through the filter media. The flow of backwash water is regulated to a rate that will separate the individual grains of media and suspend them in the flow of water. When the media is thus expanded, the grains scrub each other and the dirt particles are flushed out. Backwashing continues until the filter is clean, usually about five to ten minutes are required.

In gravity filters, the backwash water is collected at the top of the filter in troughs that drain it away to waste. In pressure filters, the backwash water is piped to waste by manipulating the proper valves.

The backwash water supply system should provide a maximum upward flow rate of 15 to 20 GPM/sq ft (10 to 13.6 mm/sec or 10 to 13.6 liters per sec/sq m). This is common for sand media. The actual flow rate required for satisfactory backwash will depend on the size and specific gravity of the media and the temperature of the water. Thus a lower flow rate will be necessary for anthracite than for sand. And a lower flow rate will be necessary when the water is cold than when it is warm. In any case, backwash flow must be adequate to lift the individual grains of filter media and expand the filter bed so the foreign matter collected in the bed can be flushed out. Separating the grains of media allows them to scrub each other clean of the coating of floc or dirt. Typically the filter bed will be expanded to 120 to 150 percent of its normal depth. However, the operator must be careful that the flow rate is not so high that the filter media itself is flushed out of the filter and lost during backwashing. See Example 9.

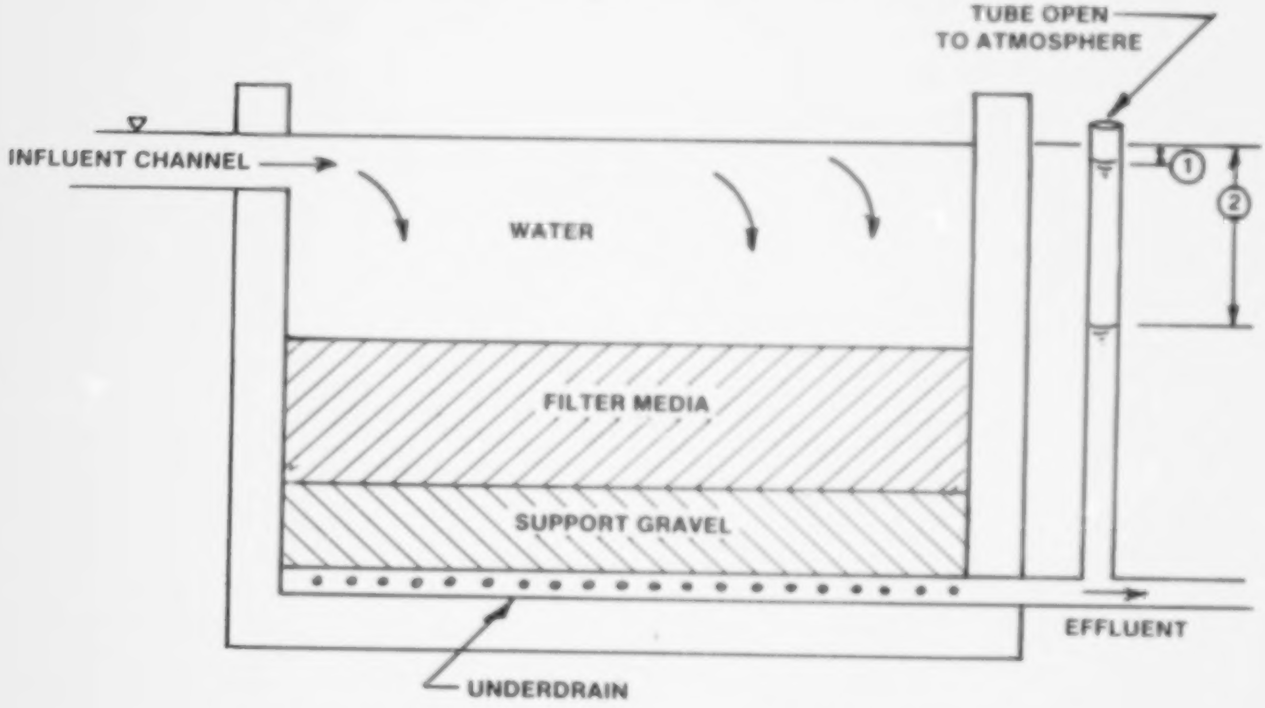
The frequency of backwashing may vary from a few hours to a few days depending on how quickly the filter plugs or on the quality of the filtered water. The filter head loss gages indicate how quickly the filters are plugging and when they need backwashing. Under unfavorable conditions when there is lots of suspended matter in the water being filtered, the filter will plug rapidly and may require backwashing several times a day. At other times when the water to be filtered contains only small amounts of suspended matter, the filter will plug slowly and it may operate from several days up to a week before backwashing is required.

However, backwashing is also required whenever the filtered water quality becomes unacceptable. If the turbidity of the filtered water suddenly increases above the level permitted by standards, backwashing is necessary even though flow through the filter is not seriously affected by plugging.

Operators of small filter plants try to achieve the longest possible filter runs, use the minimum amount of backwash water, and try to produce the best possible filtered water quality (turbidities of less than 0.1 turbidity units is a recommended target). For good operation, you should not have to use more than two percent of your filtered water for backwashing. Depending on the quality of the source water, daily backwashing may be often enough. In some cases filters may be operated two or three days without backwashing, but longer periods are not recommended.

Surface wash jets are used on modern filters to improve the efficiency of backwashing. Surface wash is especially good for dual media and mixed media filters. The water jets may be either on a fixed grid or on a rotating arm suspended above the surface of the filtering media. Compressed air is sometimes supplied with the water to the jets. The purpose of the surface wash jets is to provide additional agitation to break up any crust or *MUDBALLS*[17] that may form at the surface of the filter bed and to improve cleaning of the media. Surface washing can be very helpful and should be used whenever available. Therefore, if a permanent system of surface wash jets is not provided, the operator should use a hand-held hose with a fire nozzle to apply a powerful blast of water to the top of the filter media. The blast of water should be applied to the exposed media before and when the backwash water first starts to flow to assist cleaning of the media.

Only fully treated water should be used for filter backwashing. Untreated or partially treated water should not be used because it will contaminate the filter media and under-



NOTE: IF A TUBE OPEN TO THE ATMOSPHERE WAS INSTALLED IN THE FILTER EFFLUENT, THEN

1. **HEAD LOSS THROUGH FILTER AT START OF RUN, AND**
2. **HEAD LOSS THROUGH FILTER BEFORE START OF BACK WASH CYCLE.**

Fig. 4.12 Head loss through a filter

---

[17] *Mudballs. Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. This material forms in filters and gradually increases in size when not removed by the backwashing process.*

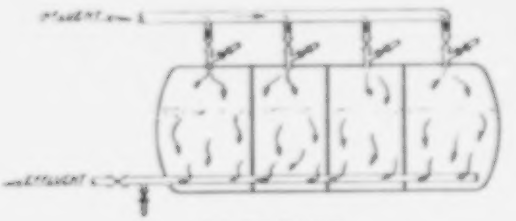
drain system, and it may leave the filter more dirty after backwashing than it was before. In gravity filter plants, the treated water for backwashing may be supplied by gravity flow from a backwash water storage tank or by special backwash pumps which draw water from the clear well. A third alternative for backwash water supply is gravity flow back from the distribution system itself.

In pressure filter plants, the backwash water is most commonly produced by the filters themselves as it is used. In this mode of operation, the treated water produced by three of the pressure filters is used to backwash the fourth. The filters are backwashed in sequence, one after another, until all are clean. This scheme requires the plant to be out of production while the filters are backwashing, but normally this is not a serious drawback. Figure 4.13 shows the in service and backwash flows for a pressure filter plant.

The waste backwash water is usually very muddy and it must be disposed of properly. Frequently the backwash water is simply flushed to waste into the nearest stream or drainage ditch. This practice is considered a source of pollution and now is no longer recommended. Disposal to a sanitary sewer system is sometimes possible. Many small plants can simply retain the backwash water in a small pond where it will evaporate or seep into the ground. If an evaporation pond is not practical, the backwash water can be contained in a tank or basin until the heavy material settles. Then the clear water can be drawn off and recycled to the inlet of the treatment plant for retreatment. The settled sludge is periodically removed to a landfill for disposal.

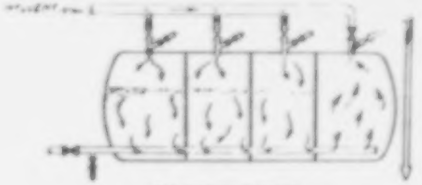
The performance of a filter must be monitored frequently or continuously if possible. Several different manufacturers supply turbidity meters (turbidimeters) that can continuously measure the turbidity of the treated water produced by a filter. Turbidimeters are also available for testing individual water samples collected on a "grab" basis; however, the continuous-reading instruments are much better for monitoring the performance of a filter because they give a rapid indication of any momentary change in quality. This rapid indication feature is indispensable when a polymer is used as a filter aid or when the operator wishes to detect the rapid rise of turbidity in the filtered water which indicates "breakthrough" and the need to backwash.

If a turbidity instrument is not available, the operator should still make an effort to monitor the performance of the filters. A reliable judgment can often be made by simply



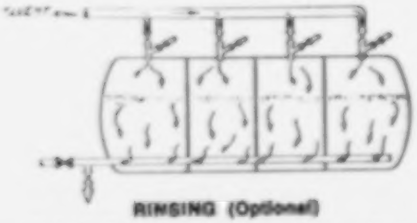
IN SERVICE

The influent water is distributed to each filter compartment, passes evenly through the media, is collected by the underdrain system and leaves the filter through the effluent valve.



BACKWASHING

The effluent valve is closed. At the same time the influent valve to one compartment is automatically closed. The backwash outlet valve to that compartment is opened. The influent water continues to filter downward through the remaining three compartments and upward through the fourth. This is repeated sequentially until the entire filter has been washed.



RINSING (Optional)

Before the filter is returned to service a rinse valve is opened allowing rinsing of the entire filter to waste. At the completion of this step the effluent valve is opened as the rinse valve closes, returning the unit to service.

Fig. 4.13 In service and backwash flows for a four-compartment pressure filter

(Permission of Watermasters, Inc., Burlingame, California)

observing the water in the clear well reservoir which receives the water from the filter. If the bottom of the reservoir is clearly visible through the full depth of water, the turbidity is probably very low. If the water is faintly cloudly and hazy, filter performance is probably substandard. A bright light beam shown through the water is usually a great help in judging the clarity. If the operator routinely observes the water every day, enough experience is soon gained to detect a change for the worse just by visual observation.

A properly operated filter plant should easily produce treated water with a turbidity of less than 1.0 Turbidity Unit and it should usually be less than 0.5 Turbidity Units. A filtered water turbidity as low as 0.1 Turbidity Units is achieved regularly by many filter plants which are well designed and operated properly. A filter plant that cannot consistently produce water with a turbidity of less than 1.0 Turbidity Unit is defective either in its design or in its operation, and corrective measures should be undertaken to correct the problem.

Most filters have similar operation and maintenance needs. If the filters are not performing satisfactorily, check the following points and make appropriate corrections.

1. Verify that the coagulation, flocculation and settling processes are performing as efficiently as possible. The turbidity of the settled water going to the filters should not exceed five Turbidity Units.
2. The rate of filtration should not exceed the design rate. Check the rate of flow controller on each filter to make sure they are preventing excessive filtration rates in any one filter.
3. The filter may need backwashing. Filters must be backwashed frequently, preferably every day. The backwash must effectively clean the filter media. Otherwise mudballs will form in the media and eventually plug the filter completely. Maintain a permanent record of the backwash frequency and duration for each filter. Check the rate of backwashing to make sure it will adequately expand the media and flush out the dirt.
4. The filter must be operated so the rate of flow changes slowly. A rapid increase in the filter rate will very likely cause the filter to produce poorer quality water. For this reason, frequently on-off operation of the filter should be eliminated. In addition, rapid operation of the backwash water valve can cause serious damage to the underdrain system. The backwash valve must always be opened *VERY* slowly.
5. The media must be inspected frequently to determine that it is in good condition. Gravity filters can be inspected easily through the open top, but pressure filters must be opened or taken apart to visually inspect the media. This should be done at least yearly and more often if necessary. Examine the media for loss in depth, mudballs, caking, surface cracks and mounding or unevenness. Remove the mudballs and replace or replenish the media as required.
6. Determine the condition of the underdrain system by observing the filters during filtering and backwashing. If the gravel layers are upset or the underdrain conduits are broken, the media will escape through the bottom of the filter and appear in the filtered water. Substantial amounts of sand in the filter effluent pipe or filtered water reservoir (clear well) indicates definitely that the underdrain system needs repair.

   If gravel appears near the surface of the media or if the surface of the media is mounded instead of level, the underdrain system should be repaired and new gravel and media installed. Sand "boils" or other evidence of uneven upward flow during backwashing are further evidence of underdrain problems.
7. Accurate gages must be provided to measure the loss of head or the pressure loss between the inlet and the outlet of the filter. These gages give a good idea of how clean the filter is and when it needs backwashing. After a filter has been backwashed, the loss of head through the filter will gradually increase as particles are removed from the water being filtered. These particles will plug the spaces in the filter material and cause the head loss to increase. The operator should maintain a permanent record of the head (pressure) loss in each filter at the beginning and end of each filter run. Variations from past readings indicate a problem.
8. Consider feeding a polymer filter aid at the inlet to the filters. Very small dosages of the proper chemical can often make a startling improvement in the efficiency of filtration.
9. When checking pressure filters with multi-cells, inspect the plates inside the filters for cracks and breaks.

Figure 4.14 shows the installation of the small treatment plant loaded on the pickup shown in Figure 4.1. This plant consists of four vertical pressure filters. Pre- and post-chlorination are used for disinfection. Alum is the coagulant. The filters are used to remove turbidity. In some installations this same type of plant is used to remove iron and manganese by changing the media.

For additional information on filtration, see Chapter 6, "Filtration," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals.

FORMULAS

To calculate the filtration rate for a rapid sand filter:

1. Determine the dimensions of the filter and surface area, and
2. Measure and record the flow of water being treated.

$$\text{Surface Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$

$$\text{Flow, gallons/min} = \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1\ \text{Million})(24\ \text{hr/day})(60\ \text{min/hr})}$$

$$\text{Flow, gallons/min} = \frac{(\text{Water Drop, ft})(\text{Surface Area, sq ft})(7.48\ \text{gal/cu ft})}{\text{Time, min}}$$

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, gal/min}}{\text{Surface Area, sq ft}}$$

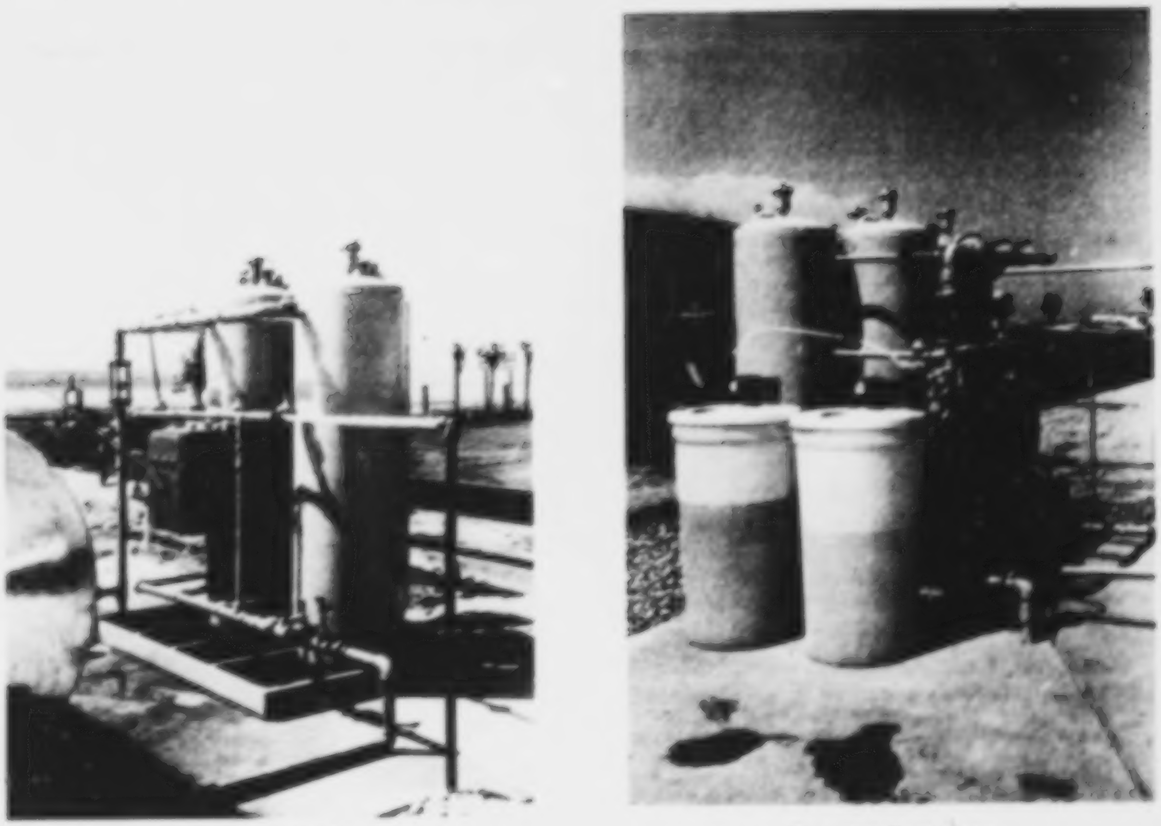
To determine the backwash flow rate for a gravity sand filter:

1. Determine the dimensions of the filter and surface area, and
2. Measure and record the flow rate of the backwash water.

$$\text{Backwash Rate, GPM/sq ft} = \frac{\text{Flow, gal/min}}{\text{Surface Area, sq ft}}$$

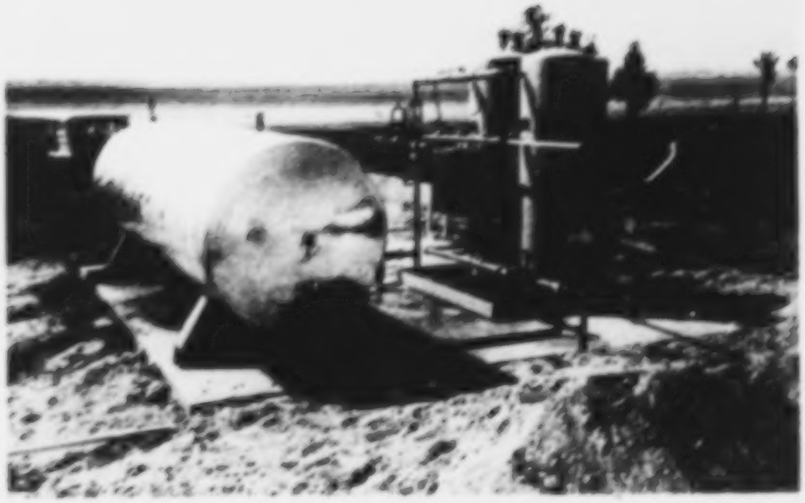
To determine the percent of water used for backwashing, divide the gallons of backwash water by the gallons of water filtered and multiply by 100 percent.

$$\text{Backwash, \%} = \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}$$



Pressure Filters

Chemical Containers



Hydropneumatic Tank

Fig. 4.14 Small pressure filtration plant

(Permission of Watermasters, Inc., Burlingame, California)

EXAMPLE 7

A water treatment plant treats a flow of 2 MGD. There are two sand filters and each filter has the dimensions of 20-feet long by 20-feet wide. Determine the filtration rate in gallons per minute per square foot of filter. NOTE: Each filter treats a flow of 1 MGD.

Known	Unknown
Length, ft = 20 ft	Filtration Rate, GPM/sq ft
Width, ft = 20 ft	
Flow, MGD = 1 MGD	

1. Calculate the filter surface area in square feet.

$$\begin{aligned}\text{Surface Area, sq ft} &= (\text{Length, ft})(\text{Width, ft})\\ &= (20\text{ ft})(20\text{ ft})\\ &= 400\text{ sq ft}\end{aligned}$$

2. Convert the flow from MGD to GPM.

$$\begin{aligned}\text{Flow, gal/min} &= \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}\\ &= \frac{(1\text{ MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}\\ &= 694\text{ gal/min}\end{aligned}$$

3. Calculate the filtration rate in gallons per minute per square foot of surface area.

$$\begin{aligned}\text{Filtration Rate, GPM/sq ft} &= \frac{\text{Flow, gal/min}}{\text{Surface Area, sq ft}}\\ &= \frac{694\text{ gal/min}}{400\text{ sq ft}}\\ &= 1.7\text{ GPM/sq ft}\end{aligned}$$

EXAMPLE 8

To check on the valve position of a controller in a filter the influent valve to the filter was closed for five minutes. During this time period the water surface in the filter dropped 1.25 feet (1 ft-3 in). The surface area of the filter is 400 square feet. Estimate the flow in gallons per minute.

Known	Unknown
Time, min = 5 min	Flow, GPM
Water Drop, ft = 1.25 ft	
Surface Area, sq ft = 400 sq ft	

Calculate the flow in gallons per minute.

$$\begin{aligned}\text{Flow, GPM} &= \frac{(\text{Water Drop, ft})(\text{Surface Area, sq ft})(7.48\text{ gal/cu ft})}{\text{Time, min}}\\ &= \frac{(1.25\text{ ft})(400\text{ sq ft})(7.48\text{ gal/cu ft})}{5\text{ min}}\\ &= 748\text{ GPM}\end{aligned}$$

EXAMPLE 9

Estimate the backwash rate for the filter in Example 7 if there are two backwash pumps capable of delivering 4000 GPM each. The total backwash flow is 8000 GPM.

Known	Unknown
Surface Area, sq ft = 400 sq ft	Backwash Rate, GPM/sq ft
Backwash Flow, GPM = 8000 GPM	

Calculate the backwash rate in gallons per minute per square foot of surface area.

$$\begin{aligned}\text{Backwash Rate, GPM/sq ft} &= \frac{\text{Backwash Flow, gal/min}}{\text{Surface Area, sq ft}}\\ &= \frac{8000\text{ GPM}}{400\text{ sq ft}}\\ &= 20\text{ GPM/sq ft}\end{aligned}$$

EXAMPLE 10

During a filter run the total volume of water filtered was 1.20 million gallons. When the filter was backwashed, 18,000 gallons of water was used. Calculate the percent of filtered water used for backwashing.

Known	Unknown
Water Filtered, gal = 1,200,000 gal	Backwash, %
Backwash Water, gal = 18,000 gal	

Calculate the percent of water used for backwashing.

$$\begin{aligned}\text{Backwash, \%} &= \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}\\ &= \frac{(18{,}000\text{ gal})(100\%)}{1{,}200{,}000\text{ gal}}\\ &= 1.5\%\end{aligned}$$

QUESTIONS

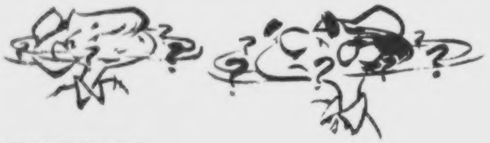
Write your answers in a notebook and then compare your answers with those on page 218.

4.4A What is included in the suspended matter removed by filtration?

4.4B Why does anthracite and sand stay separated during and after backwashing?

4.4C What is a "mixed media" filter?

4.4D Under what conditions will mudballs form in filters?



4.5 DISINFECTION

The purpose of disinfection in domestic water treatment is to kill any disease-causing organisms that may be present. There are several types of disease-causing organisms and each type has different characteristics that are important to understand.

1. Bacteria

Bacteria are microscopic organisms. Individual bacteria are usually so small they are invisible to the naked eye. Therefore it is impossible to tell if bacteria are present simply by looking at the water. A glass of water may be sparkling clear and appear to be pure but actually contain millions of bacteria.

Most bacteria are harmless but a few types cause serious illness and even death in humans. Some bacterial diseases transmitted by drinking contaminated water include typhoid fever, paratyphoid fever, bacillary dysentery and cholera.

2. Virus

Virus agents are very small organisms, much smaller than bacteria, and they too can cause serious illness in humans. Infectious hepatitis and possibly poliomyelitis are two virus diseases that can be transmitted by contaminated drinking water. So called "sewage poisoning," acute intestinal upset caused by drinking sewage-contaminated water, may also be caused by virus agents.

3. Protozoa

Protozoa are microscopic animals that are also too small to be detected by the naked eye. Among the waterborne diseases they cause are amoebic dysentery and giardiasis (gee-are-DYE-uh-sis).

These three types of organisms (bacteria, virus and protozoa) differ in their resistance to chlorine, the most common disinfectant. The bacteria are readily killed by the chlorine residual (0.2 to 0.5 mg/*L*) normally maintained in domestic water from a treatment plant. Most viruses are significantly more resistant to chlorine than are bacteria. Therefore, higher chlorine concentrations and longer contact times are necessary to kill virus agents. The protozoa are the most resistant to chlorine. They normally are not killed by the concentrations of chlorine ordinarily used in water treatment. Therefore, operators must rely on the processes of coagulation, flocculation, settling and filtration for physical removal of protozoa rather than depend on disinfection to kill the organisms.

The processes of coagulation, flocculation, settling and filtration can remove a high percentage of the disease organisms from a water supply. However, the operator cannot rely on these processes for 100 percent removal of disease organisms. Disinfection must be applied to all surface water sources to insure that the water will be entirely safe and free of harmful organisms. Groundwater sources from properly constructed wells and springs may be free of contamination and may not require disinfection.

Nearly all domestic water supplies are disinfected with chlorine, although iodine, ozone and ultraviolet radiation are also used occasionally. Chlorine is available in several forms. Gaseous chlorine can be purchased as liquid chlorine in steel cylinders. As chlorine gas is removed from the cylinder, the liquid chlorine evaporates and produces more gas. Chlorine can also be purchased in the form of liquid bleach, a solution of sodium hypochlorite in water. Laundry bleach available from grocery stores is 5.25 percent chlorine and commercial strength bleach available from swimming pool suppliers or chemical companies is usually 12.5 percent chlorine. Chlorine compounds in a solid form, granular or tablets, can also be purchased from swimming pool suppliers and chemical companies. These compounds of chlorine contain calcium hypochlorite. Calcium hypochlorite in solid form contains 65 percent available chlorine. This means that if you add ten pounds of calcium hypochlorite to water, you are actually adding 6.5 pounds of chlorine (10 lbs × 0.65 = 6.5 lbs). Chlorine dioxide (ClO_2) is another form of chlorine used to disinfect drinking water. All forms of chlorine are hazardous chemicals that can cause serious injury and damage if they are not stored and used properly.

The form of chlorine used at the treatment plant will determine the type of chlorine feeder that is needed. If chlorine gas is used, it must be fed through a *CHLORINATOR*. The chlorinator not only controls and measures the flow of chlorine gas but also dissolves it in water so it can be safely injected into the water supply (Figure 4.15).

If chlorine in the form of liquid bleach (sodium hypochlorite) or a granular compound (calcium hypochlorite) is used, it is mixed with water to make a hypochlorite solution. Then this solution is injected into the water supply by a chemical solution feed pump called a *HYPOCHLORINATOR*.

Small water plants most frequently use hypochlorite forms of chlorine because these are safer to handle and the feeder pumps are relatively inexpensive. Larger plants use chlorine gas because it is less expensive than hypochlorites and because gas chlorinators are usually more reliable and require less attention by the operator than a hypochlorinator.

The following factors have an important effect on disinfection of water with chlorine.

1. *CONCENTRATIONS OF CHLORINE*

   The higher the chlorine concentration, the faster and more complete will be the disinfection.

2. *TIME OF CHLORINE CONTACT*

   The longer that water is in contact with chlorine, the greater will be the degree of disinfection achieved. Short-circuiting of flow through basins and tanks must be avoided because it can drastically shorten the time of chlorine contact. *CLEAR WELLS* which store treated water are used to provide adequate contact time.

3. *THE pH OF THE WATER*

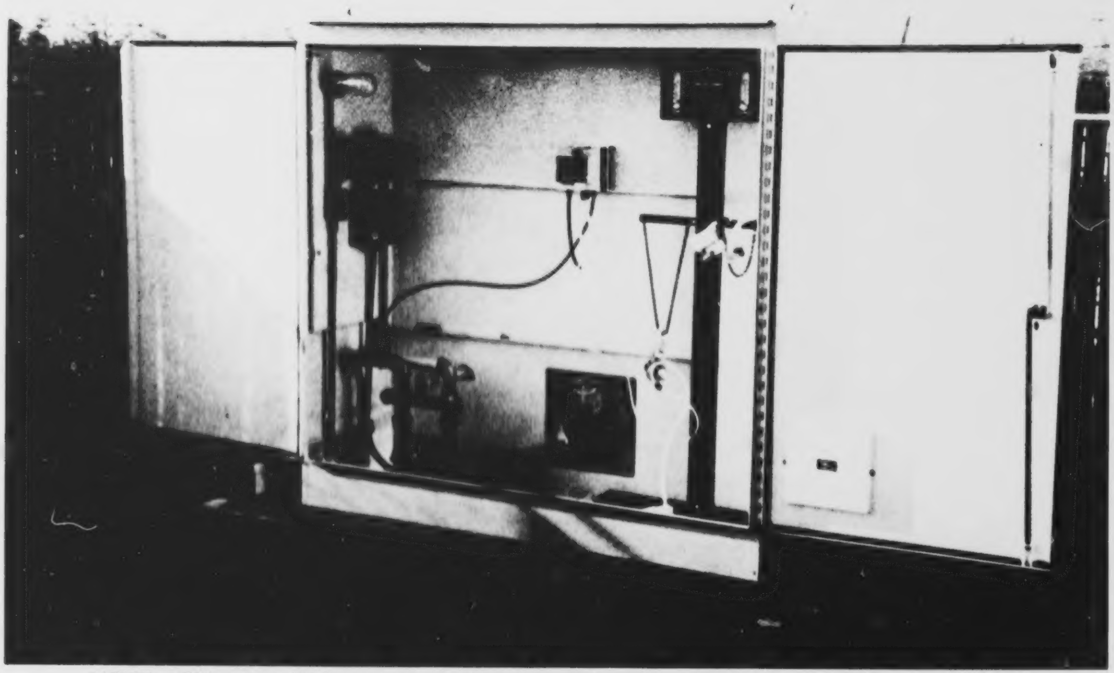
   The pH determines whether the chlorine is in the form of hypochlorous acid, a powerful disinfectant, or in the form of hypochlorite ion, which is a much weaker disinfectant. For best results, the pH should be less than 7.5.

4. *WATER TEMPERATURE*

   Chlorine requires more time to kill organisms in cold water than in warm water. A decrease in the water temperature from summer to winter may require twice the contact time to achieve the same degree of disinfection.

5. *DEGREE OF MIXING*

   Any organisms not exposed to chlorine will not be killed. Therefore, mixing of the chlorine and the water must be rapid and complete to insure that chlorine comes in contact with all the organisms present.



NOTE: Chlorine cylinders are placed on the scales at the right and secured by the chains.

Fig. 4.15 Small chlorination system

(Permission of Watermasters, Inc., Burlingame, California)

6. *CLARITY IN WATER*

Organisms that are encased in a covering of suspended particles, mud or trash may be so protected from the chlorine that the chlorine never penetrates to the organisms. It is important to remove as much suspended matter as possible so it does not "shield" organisms from chlorine or consume the chlorine before it is effective in killing the organisms.

7. *PRESENCE OF INTERFERING SUBSTANCES*

Chlorine is a very active chemical and it reacts quickly with many substances. These chemical reactions can consume the chlorine or convert it to forms that are poor disinfectants. Ammonia is one of the most troublesome substances because it combines readily with chlorine to form chloramine compounds. Chloramines are much weaker disinfectants than free chlorine. Sources of ammonia in water include the effluent from a wastewater treatment plant or seepage from the subsurface leaching system of a septic tank. Other substances which react with chlorine and consume it include dissolved iron and manganese, hydrogen sulfide and organic matter.

8. *POINTS OF CHLORINE APPLICATION*

Provisions should be made to feed chlorine at several different locations in the plant. The place of feed may vary from time to time depending on source water quality. If natural organics are not present in the source water, chlorination early in the treatment process can provide effective disinfection and reduce chlorine costs.

In addition to controlling the above factors, the operator must have reliable chlorination equipment and it must be properly maintained and competently operated. An important part of operating the chlorinator is to measure the concentration of chlorine in the water on a daily basis. This measurement is made with a chlorine test kit (Figure 4.16). Many brands of chlorine test kits are available. Most of them consist of a clear sample vial and a set of color standards. The reagent, which produces a color whose intensity is proportional to the chlorine concentration, is added to the vial containing the water sample. The color that forms in the sample is then compared with the known color standards to determine the chlorine concentration. Previously, a chemical solution containing orthotolidine reagent, which produces a yellow color with chlorine, was used in all chlorine test kits. Orthotolidine (O.T.) is still used in the low cost chlorine test kits that are supplied for testing swimming pool waters. However, for testing domestic water supplies a new reagent called DPD (diethyl-p-phenylene diamine) is much preferred because it is more accurate and versatile. The DPD method is subject to fewer interferences than O.T. and it accurately measures both free and total chlorine residuals.

The operators must be acquainted with the three types of chlorine residuals that can be found in treated water.

1. *FREE*

Free available chlorine residual includes that chlorine in the form of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). Hypochlorous acid is the most effective disinfectant form of chlorine. Hypochlorite ion is much less effective as a disinfectant than hypochlorous acid. The pH determines whether the free chlorine is in the form of hypochlorous acid or hypochlorite ion. The lower the pH, the greater the percent of hypochlorous acid.

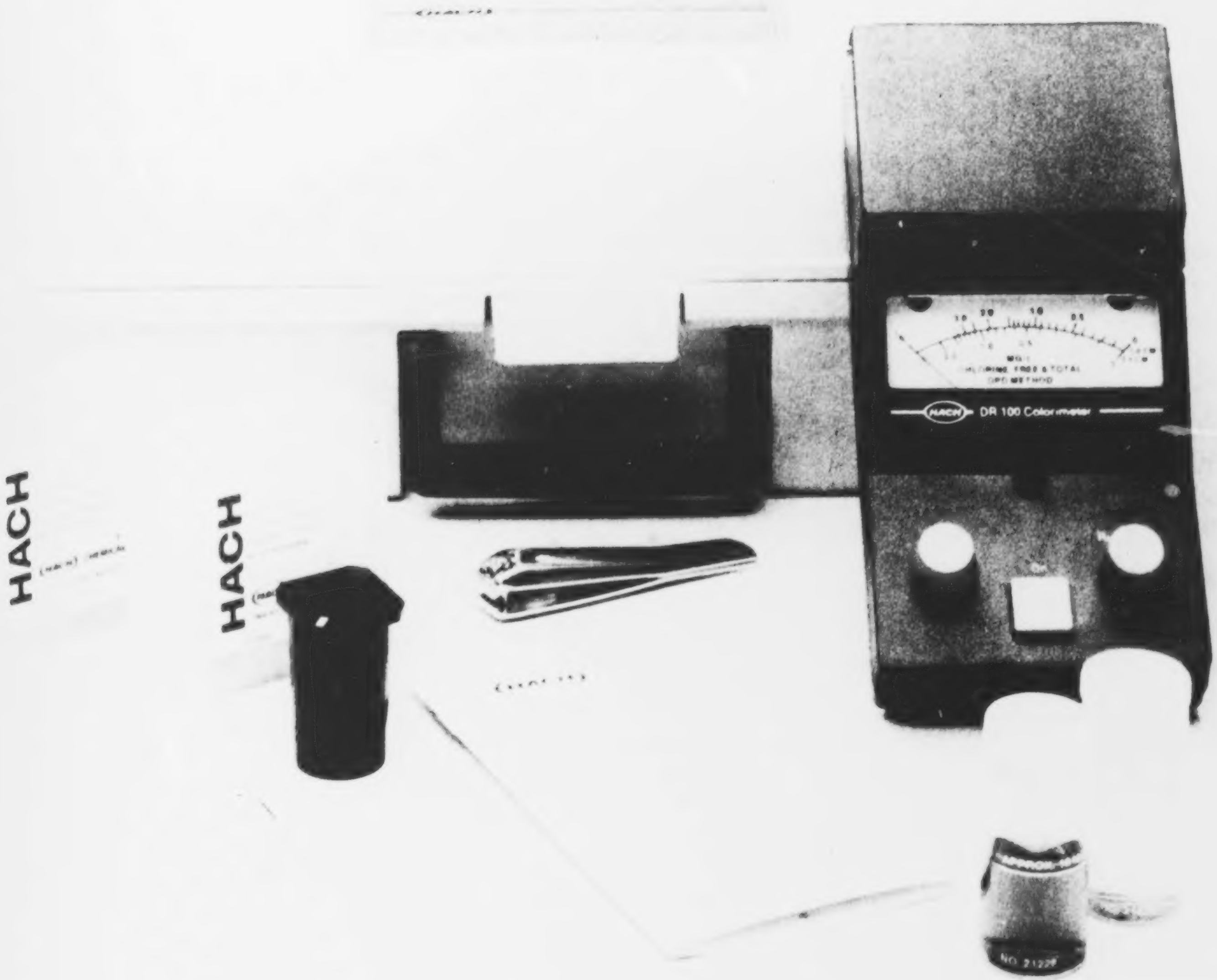

HACH
HACH
MG/L
CHLORINE, FREE & TOTAL
DPD METHOD
HACH DR 100 Colorimeter
NO. 21229

Fig. 4.16 Chlorine test kit

(Permission of HACH Company)

2. *COMBINED*

   Combined available chlorine residual includes that chlorine in the three chloramine forms (monochloramine, dichloramine, and nitrogen trichloride) which are produced when chlorine reacts with ammonia. Combined chlorine requires up to 100 times the contact time or at least 25 times the chlorine concentration to achieve the same degree of disinfection as free available chlorine.

3. *TOTAL*

   The total chlorine residual is the sum of the free residual and the combined residual.

Chlorine residual test kits measure the free available chlorine residual and the total chlorine residual. The combined available chlorine residual is the difference. For example, a test kit could measure the free chlorine residual as one mg/*L* and the total chlorine residual as three mg/*L*. The combined available chlorine residual would be two mg/*L* (3 mg/*L* − 1 mg/*L* = 2 mg/*L*).

Operators should strive to maintain a free chlorine residual to accomplish disinfection and to avoid depending on the much weaker combined chlorine residual. Thus, in performing a chlorine residual test, the small system operator should make sure that the test result indicates only the *FREE* chlorine residual concentration.

Operators of small treatment plants frequently ask, "What chlorine residual should I maintain to guarantee that the finished water is adequately disinfected?" This is a very important question and one that must be answered correctly. But it is impossible to give a simple answer covering all situations because, as already explained, the required chlorine concentration is related to the contact time, the pH and the water temperature.

A reference book, *HANDBOOK OF CHLORINATION*[18] by George Clifford White, describes a workable method for calculating the required chlorine concentration under various conditions. The calculation uses the following formula:

$$C \times T = A$$

where C = the free available chlorine residual concentration in milligrams per liter,

T = the chlorine contact time in minutes, and

A = a number which varies with the pH as shown in Table 4.1

TABLE 4.1 RELATIONSHIP BETWEEN pH AND A

pH range	A (for cold water, 0° to 5°C)
7.0 - 7.5	12
7.5 - 8.0	20
8.0 - 8.5	30
8.5 - 9.0	35

For example, suppose in a particular small water plant that the minimum chlorine contact time from the point of chlorine injection to the entrance of the distribution system is thirty minutes. Then for the formula, T = 30. The pH of the water was found to be 7.2 and the water temperature during the winter months is usually just above freezing, say 1° or 2° Celsius. Then from Table 4.1, the value of A in this case is 12. Substituting these values in the formula we obtain:

$$C \times T = A$$

$$C \times (30) = (12)$$

Solving for C,

$$C, \text{mg}/L = \frac{12}{30}$$

$$= \frac{4}{10}$$

$$= 0.4 \text{ mg}/L \text{ free chlorine residual}$$

This calculation tells us that good disinfection of the water supply will be accomplished under the existing conditions by maintaining a free chlorine residual of at least 0.4 mg/*L* for the thirty-minute contact time. Notice that a stronger chlorine residual would be required if the pH were increased, say to 8.3. Then, A = 30.

$$C \times T = A$$

$$C \times (30) = (30)$$

or

$$C = \frac{30}{30}$$

$$= 1.0 \text{ mg}/L \text{ free chlorine residual}$$

Sometimes you may increase the chlorine dose setting on your chlorinator and *THE CHLORINE RESIDUAL MAY ACTUALLY DROP* (Figure 4.17, *BREAKPOINT CHLORINATION*)![19] This can happen when ammonia is present. Also under these conditions you may obtain complaints that your water tastes like chlorine. The solution to this problem is to increase the chlorine dose even more! For additional information on breakpoint chlorination, see Chapter 9, "Disinfection." You are at the proper setting if:

1. You are maintaining the chlorine residual from the above calculations,
2. An increase in the chlorinator setting will produce a calculated chlorine dose increase of 0.1 mg/*L* and the resulting actual chlorine residual increases by 0.1 mg/*L*,

---

[18] *HANDBOOK OF CHLORINATION by George Clifford White. Available from Van Nostrand Reinhold, 7625 Empire Drive, Florence, Kentucky 41042. Price $89.50.*

[19] *Breakpoint Chlorination. Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.*

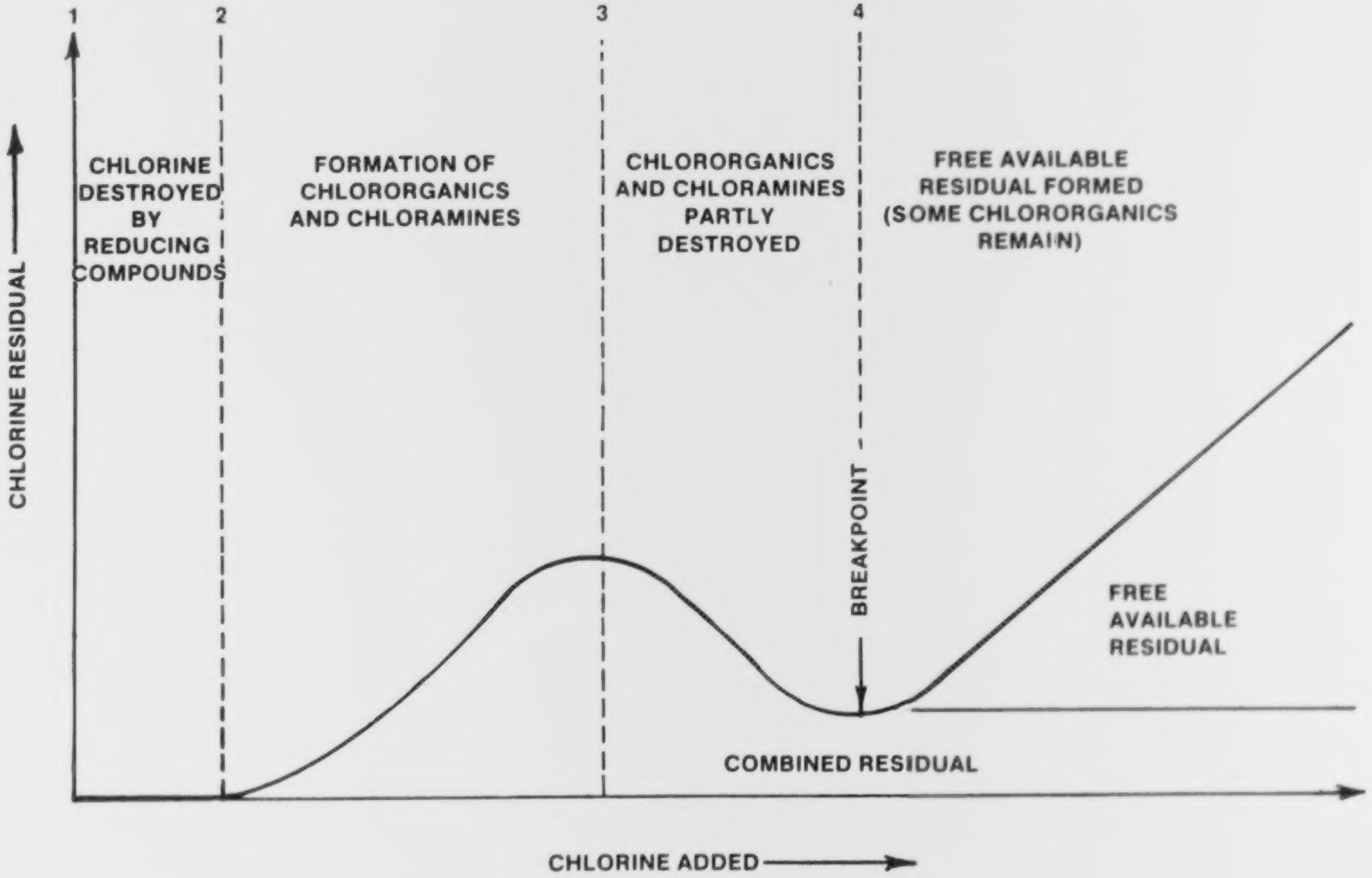


Fig. 4.17 Breakpoint chlorination curve

3. Chlorine residual tests at the far end of the distribution system produce chlorine residuals of at least 0.2 mg/L, and
4. Coliform test results from throughout the distribution system are negative.

Another important part of chlorinator operation is keeping adequate records. The records must be legible and kept in an organized format. They should be written down in a permanent manner that can be preserved indefinitely for future reference. Records scribbled with a dull pencil on assorted scraps of paper are worthless and suggest incompetence.

The records should show the date and time the chlorinator was inspected, the flow rate of the water being treated, the total gallons of water treated, the feed rate of the chlorinator, the pounds of chlorine used, the calculated chlorine dosage, the chlorine residual concentration in the water as measured with the test kit, and the operator's name. The operator can conveniently tabulate this vital information on a standard record sheet similar to those in Tables 4.2 and 4.3.

Chlorinators not in service require more maintenance than those in service. The operator must be alert to spot failures and repair the equipment quickly because lack of disinfection is not, of course, acceptable. If possible the operator should have a spare chlorinator on hand that can replace the failing unit. If not, the treatment plant must be shut down until the chlorinator is repaired. If the plant must operate without a chlorinator, consumers must be notified to boil all drinking water. The operator should save the manufacturer's operation manual for reference and keep repair parts in stock at all times. Contacts should be established with the chlorinator supplier or manufacturer so that service and parts can be obtained quickly. A program of periodic maintenance on chlorination equipment will prevent the vast majority of chlorinator failures. Regular disassembly and cleaning of the chlorinator and replacement of critical parts is recommended insurance against a breakdown.

If a gas chlorinator is not feeding properly, the operator should check the items listed below.

1. The chlorine feed rate may not be properly adjusted. Reset it to the desired level.
2. The chlorine gas supply may be interrupted. The gas cylinder may be empty or the gas valve on the cylinder may be closed. Also, the chlorine tubing from the gas cylinder to the chlorinator may be plugged.
3. Are you trying to draw too much chlorine gas from the cylinder? If the withdrawal rate is too high, the liquid chlorine will not evaporate fast enough. High velocities of chlorine gas in the chlorine supply line will remove heat and cause a frost to form on the line. This can cause the chlorine gas to *RELIQUEFY.*[20] This liquid chlorine can plug the supply line and no more chlorine gas will flow. Operators refer to this condition as a "frozen" chlorine supply line: *BE VERY CAREFUL BECAUSE IF YOU DISCONNECT THE SUPPLY,* the liquid chlorine can evaporate again and send liquid chlorine shooting out the end of the disconnected line.
4. The chlorinator may not be drawing a vacuum. Check the water supply to the injector for adequate flow and make sure the injector is not plugged with debris.
5. The internal mechanism of the chlorinator may be malfunctioning. A broken diaphragm, a weak spring or a leaking gasket will cause a malfunction. Replace the necessary parts and clean the chlorinator thoroughly using the cleaning solvents recommended by the manufacturer.

If a hypochlorinator is not feeding properly, check these points.

1. Adjust the hypochlorinator to feed the desired dosage.
2. The hypochlorite solution may be used up.
3. The intake tubing in the hypochlorite solution tank may be plugged with sediment.
4. The diaphragm in the hypochlorinator may be ruptured.
5. The inlet and outlet poppet valves in the hypochlorinator may be malfunctioning.
6. The drive belt may be broken or slipping.
7. The electrical supply to the hypochlorinator may be interrupted.
8. The feed line from the hypochlorinator to the injection point may be plugged or broken.
9. There may be excessive backpressure at the point of injection which the hypochlorinator cannot overcome.
10. The hypochlorite solution may freeze in the tubing and other small conduits through which it flows. Provide an insulated, heated enclosure for the equipment.

The biggest problem with hypochlorinators is that they can develop calcium deposits if you are using calcium hypochlorite. Hypochlorinators can be cleaned with a weak acid (vinegar or muriatic acid). If you have only one hypochlorinator, turn off the water being disinfected so no unchlorinated water can enter your clear well or distribution system. Pump the acid through the entire pump (hypochlorinator or chemical feed pump, they are the same) and into a waste or drain line. This procedure allows for the cleaning of all feed lines, valves and equipment. If this procedure is followed on a regular or routine basis, the pump will never have to be taken apart for cleaning.

If the operator has problems achieving adequate disinfection of the water or maintaining a chlorine residual, one or more of the following problems could be the cause.

1. The chlorinator is not feeding. Inspect the equipment and determine that the chlorinator is operating properly.
2. The chlorine dosage is inadequate. Readjust the chlorinator to feed the proper dosage. Never mix more than a two or three-day supply of hypochlorite solution. Hypochlorite solutions lose their strength in time and this fact has the effect of changing the feed rate.

---

[20] *Reliquefaction (re-LICK-we-FACK-shun). The return of a gas to the liquid state; for example, a condensation of chlorine gas to return to its liquid form by cooling.*

TABLE 4.2 CHLORINATION RECORD FOR GAS CHLORINATOR

CHLORINATION RECORD
FOR
GAS CHLORINATOR

REPORT NO ______
WATER SUPPLIER ______
SYSTEM NAME ______ SYSTEM NO. ______
FOR WEEK OF ______ THRU ______ 19__
OPERATOR ______

DAY	DATE	TIME	CHLORINE RESIDUALS, mg/l			WATER PRODUCTION			CHLORINATION TREATMENT						
			#1	#2	#3	PLANT OPERATING RATE — GPM	WATER METER READING (GALLONS)	GALLONS OF WATER TREATED	CHLORINATOR FEED RATE LBS/24 HRS	WEIGHT OF CHLORINE AND CONTAINER	WEIGHT OF EMPTY CONTAINER	WEIGHT OF CHLORINE REMAINING	POUNDS OF CHLORINE USED	AVG. CHLORINE DOSE FOR PAST DAY (CALCULATED) NOTE 1	INSTANTANEOUS CHLORINE DOSE (CALCULATED) NOTE 2
COLUMN NUMBER			1	2	3	4	5	6	7	8	9	10	11	12	13
SUN.															
SAT.															
FRI.															
THUR.															
WED.															
TUE.															
MON.															
READINGS FORWARD			▨	▨	▨	▨		▨	▨				▨	▨	▨
WEEKLY TOTALS →															

REPORT SUBMITTED BY:

______
SIGNATURE

REMARKS:

NOTE 1: AVG. CHLORINE DOSE (mg/l)

$$= \frac{(\text{LBS. OF } CL_2 \text{ USED})(120{,}000)}{\text{GAL OF WATER TREATED}} = \frac{(\text{COL 11})(120{,}000)}{(\text{COL 6})}$$

NOTE 2: INSTANTANEOUS CHLORINE DOSE mg/l

$$= \frac{(\text{CHLORINATOR FEED RATE})}{(.012)(\text{PLANT OPERATING RATE — GPM})} = \frac{(\text{COL. 7})}{(.012)(\text{COL. 4})}$$

TABLE 4.3 OPERATION RECORD FOR SODIUM HYPOCHLORINATOR

OPERATION RECORD FOR SODIUM HYPOCHLORINATOR

REPORT NO ______________

WATER SUPPLIER ______________

SYSTEM NAME ______________ SYSTEM NO ______________

FOR WEEK OF ______________ THRU ______________ 19 ____

ITEM A.	STRENGTH OF BLEACH USED	5.25%	12.5%	1.0%
ITEM B.	POUNDS OF CHLORINE PER GALLON	0.44 LBS.	1.04 LBS.	0.083 LBS.

ITEM C. SIZE OF CHLORINE SOLUTION TANK: ______________ GALLONS

ITEM D. SIDEWALL DEPTH OF SOLUTION TANK: ______________ INCHES

ITEM E. STRENGTH OF SOLUTION: EACH GALLON OF BLEACH IS ADDED TO ______________ GALLONS OF WATER.

ITEM F. GALLONS OF BLEACH IN A FULL TANK OF SOLUTION: ______________ GALLONS.

ITEM G. POUNDS OF CHLORINE IN ONE INCH OF SOLUTION DEPTH: ______________ POUNDS PER INCH DEPTH.

$$\frac{\text{(GAL. BLEACH IN FULL TANK) (POUNDS CHLORINE/GALLON)}}{\text{(SIDEWALL DEPTH OF SOLUTION TANK)}} \qquad \frac{\text{(ITEM F) X (ITEM B)}}{\text{(ITEM D)}}$$

			CHLORINE RESIDUALS mg/l			WATER PRODUCTION			CHLORINATION TREATMENT					
DAY	DATE	TIME	#1	#2	#3	PLANT OPERATING RATE G.P.M.	WATER METER READING (GALLONS)	GALLONS OF WATER TREATED	FEEDER SETTING	INCHES OF SOLUTION IN TANK	INCHES OF SOLUTION USED	POUNDS OF CHLORINE USED (ITEM G) TIMES (COLUMN 8)	AVERAGE CHLORINE DOSE mg/l (NOTE 1)	QUARTS OF BLEACH TO BE ADDED (NOTE 2)
COLUMN NUMBER			1	2	3	4	5	6	7		8	9	10	11
SUN.														
SAT.														
FRI.														
THUR.														
WED.														
TUE.														
MON.														
READINGS FORWARD														
WEEKLY TOTALS →														

REPORT SUBMITTED BY:

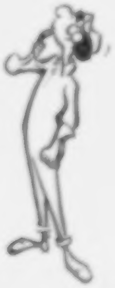
____

SIGNATURE

NOTE 1: AVG. CHLORINE DOSE (mg/l) $= \frac{\text{(LBS. OF CHLORINE USED) X (120,000)}}{\text{(GAL OF WATER TREATED)}} \quad \frac{\text{(COL 9) X (120,000)}}{\text{(COL 6)}}$

NOTE 2: QUARTS OF BLEACH TO BE ADDED $= \frac{\text{(INCHES SOLN. USED) X (4) X (GALLONS OF BLEACH IN A FULL TANK)}}{\text{(SIDEWALL DEPTH OF SOLUTION TANK)}} \quad \frac{\text{(COL 8) X (4) X (ITEM F)}}{\text{(ITEM D)}}$

3. The contact time is too short. Relocate the point of chlorine injection to increase the contact time. Eliminate short-circuiting of flow through the plant.
4. Suspended matter in the water is preventing effective disinfection. Improve clarification treatment so that turbidity is minimal.
5. The chlorine is being consumed by organic matter, dissolved gases or minerals or by sludge in basins and pipelines. Increase the chlorine dosage, clean sludge from basins and storage tanks and flush sediment from the distribution system.
6. The chlorine is being destroyed by exposure to sunlight in an uncovered storage tank. Provide a cover for the storage tank or re-chlorinate the water as it leaves the tank.



For additional information on disinfection, see Chapter 7, "Disinfection," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals.

FORMULAS

To estimate the actual average chlorine dose in milligrams per liter for a gas chlorinator:

1. Determine the weight of chlorine used, and
2. Measure and record the amount of water treated.

$$\text{Average Chlorine Dose, mg}/L = \frac{\text{Chlorine Used, lbs/day}}{(\text{Water Treated, MGD})(8.34\ \text{lbs/gal})}$$

$$= \frac{\text{lbs Chlorine}}{\text{M lbs Water}}$$

$$= \frac{\text{mg Chlorine}}{\text{1 M mg Water}}$$

$$= \text{mg Chlorine/Liter Water}$$

OR

$$\text{Average Chlorine Dose, mg}/L = \frac{(\text{Chlorine Used, lbs/day})(1{,}000{,}000)}{(\text{Water Treated, gal/day})(1\ \text{M})(8.34\ \text{lbs/gal})}$$

$$= \frac{(\text{Chlorine Used, lbs/day})(120{,}000)}{\text{Water Treated, gal/day}}$$

$$= \text{mg Chlorine/Liter Water}$$

NOTE: Chlorine used in pounds and water treated in gallons or million gallons must be for the same time interval, but not necessarily for 24 hours. The time period could be 20 hours, 27 hours or even 2 days.

To estimate the instantaneous chlorine dose in milligrams per liter for a gas chlorinator:

TABLE 4.4 INSTRUCTIONS FOR COMPLETING TABLE 4.3, "OPERATION RECORD FOR SODIUM HYPOCHLORINATOR" (See Example 12)

ITEM A and ITEM B — Circle the strength of chlorine bleach and the corresponding value for pounds of chlorine per gallon that is purchased for mixing the chlorine solution.

ITEM C — Record the capacity of the chlorine solution tank in gallons.

ITEM D — Record the sidewall depth of the solution tank when it is full.

ITEM E — Record the number of gallons of water that are added to each gallon of bleach for preparing chlorine solution.

ITEM F — Using the information in Item E, calculate the gallons of bleach in a full tank of solution.

ITEM G — Calculate the pounds of chlorine in one inch of solution depth in the tank. For example, assume that a 30-gallon solution tank is used and that the chlorine solution is made by mixing 4 gallons of water with each gallon of 5.25% household bleach (Clorox or Purex). Therefore the full 30-gallon tank will contain 6 gallons of bleach. Since each gallon of 5.25% bleach contains 0.44 pounds of chlorine, six gallons of bleach contain $(6)\times(0.44)=2.64$ pounds of chlorine. If the tank has a sidewall depth of 36 inches, there are $(2.64)\div(36)=0.073$ pounds of chlorine in each inch of solution depth in the tank.

Columns 1 through 7 in the daily record form are self-explanatory.

COLUMN 8 — Measure the inches of chlorine solution used from the tank and record it in Column 8.

COLUMN 9 — Calculate the pounds of chlorine used by multiplying the inches of chlorine solution used (Column 8) times the pounds of chlorine in one inch of solution depth (Item 7). Record the answer in Column 9.

COLUMN 10 — Calculate the average chlorine dose by multiplying the pounds of chlorine used (Column 9) times 120,000 and divide by the gallons of water treated (Column 6). Record the answer in Column 10.

COLUMN 11 — To refill the solution tank proceed as follows. Multiply the inches of solution used from the tank times four. Then multiply that answer times the gallons of bleach that are in the tank when it is full, in this example, 6 gallons. Divide this answer by the total sidewall depth of the solution tank (36") to obtain the number of *QUARTS* of bleach that should be added to the tank. Enter the answer in Column 11. After the bleach is added, fill the tank to the top with clean water. This procedure will maintain the chlorine solution in the tank at a uniform strength.

$$\frac{(\text{Inches of Solution Used}) \times (4) \times (\text{Gallons of Bleach in a Full Tank})}{(\text{Sidewall Depth of Solution Tank})} = \frac{(\text{Col. 8}) \times (4) \times (\text{Item F})}{(\text{Item D})}$$

1. Record the chlorinator feed rate setting, and
2. Measure and record the flow rate for the water being treated.

$$\text{Flow Rate, MGD} = \frac{(\text{Flow, gal/min})(1\ \text{M})(60\ \text{min/hr})(24\ \text{hr/day})}{(1{,}000{,}000)}$$

$$\text{Instantaneous Chlorine Dose, mg/}L = \frac{\text{Chlorinator Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34\ \text{gal/day})}$$

$$\text{OR} = \frac{\text{Chlorinator Feed Rate, lbs/day}}{(\text{Flow, GPM})(0.012)}$$

To select the chlorinator feed rate setting in pounds of chlorine per 24 hours (lbs/day):

1. Determine the desired chlorine dose, and
2. Measure and record the flow rate for the water being treated.

$$\text{Chlorinator Feed Rate, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\ \text{lbs/gal})$$

To estimate the actual average chlorine dose in milligrams per liter of a hypochlorinator system:

1. Determine the dimensions and volume of the hypochlorite solution container,
2. Determine the number of gallons of water added to each gallon of hypochlorite (bleach) in the solution tank, and
3. Measure and record the amount of water treated.

$$\text{Total Chlorine, lbs} = (\text{Chlorine, lbs/gal})(\text{Bleach, gal})$$

$$\text{Chlorine Used, lbs} = \frac{(\text{Total Chlorine, lbs})(\text{Chlorine Used, in})}{(\text{Depth of Tank, in})}$$

$$\begin{aligned}\text{Average Chlorine Dose, mg/}L &= \frac{(\text{Chlorine Used, lbs})(1{,}000{,}000)}{(\text{Water Treated, gal})(1\ \text{Million})(8.34\ \text{lbs/gal})}\\ &= \frac{\text{lbs Chlorine}}{\text{M lbs Water}}\\ &= \frac{\text{mg Chlorine}}{\text{M mg Water}}\\ &= \text{mg Chlorine/Liter Water}\end{aligned}$$

EXAMPLE 11

Estimate the average chlorine dose in mg/*L* for a chlorinator that used 10 pounds of chlorine to treat 500,000 gallons (0.5 million gallons of water).

Known	**Unknown**
Chlorine Used, lbs = 10 lbs	Average Chlorine Dose, mg/*L*
Water Treated, M Gal = 0.5 M Gal	

Calculate the average chlorine dose in mg/*L*.

$$\begin{aligned}\text{Average Chlorine Dose, mg/}L &= \frac{\text{Chlorine Used, lbs}}{(\text{Water Treated, M Gal})(8.34\ \text{lbs/gal})}\\ &= \frac{10\ \text{lbs Chlorine}}{(0.5\ \text{M Gal Water})(8.34\ \text{lbs/gal})}\\ &= \frac{10\ \text{lbs Chlorine}}{4.17\ \text{M lbs Water}}\\ &= 2.4\ \text{mg/}L\end{aligned}$$

EXAMPLE 12

Estimate the instantaneous chlorine dose in mg/*L* if the chlorinator feed rate is set at 12 pounds per 24 hours and the flow is 300 gallons.

Known	**Unknown**
Chlorine Feed, lbs/day = 12 lbs/day	Instantaneous Chlorine Dose, mg/*L*
Flow, GPM = 300 GPM	

1. Convert the flow from GPM to MGD.

$$\begin{aligned}\text{Flow, MGD} &= \frac{(\text{Flow, gal/min})(1\ \text{M})(60\ \text{min/hr})(24\ \text{hr/day})}{(1{,}000{,}000)}\\ &= \frac{(300\ \text{gal/min})(1\ \text{M})(60\ \text{min/hr})(24\ \text{hr/day})}{(1{,}000{,}000)}\\ &= 0.432\ \text{MGD}\end{aligned}$$

2. Calculate the instantaneous chlorine dose in mg/*L*.

$$\begin{aligned}\text{Instantaneous Chlorine Dose, mg/}L &= \frac{\text{Chlorinator Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34\ \text{lbs/gal})}\\ &= \frac{12\ \text{lbs/day}}{(0.432\ \text{MGD})(8.34\ \text{lbs/gal})}\\ &= 3.3\ \text{mg/}L\end{aligned}$$

EXAMPLE 13

Estimate the actual average chlorine dose in milligrams per liter from a hypochlorinator. The depth of hypochlorite solution dropped 10 inches while treating 100,000 gallons of water. The strength of bleach used is 5.25 percent and contains 0.44 lbs of chlorine per gallon of bleach. For every gallon of bleach added to the container, four gallons of water are added. The full mark on the container is at 50 gallons (10 gallons of bleach and 40 gallons of water). When the container is full, there are 50 inches of hypochlorite solution.

Known	**Unknown**
Chlorine Used, in = 10 in	Average Chlorine Dose, mg/*L*
Water Treated, gal = 100,000 gal	
Bleach, lbs/gal = 0.44 lbs/gal	
Bleach Used, gal = 10 gal	
Depth of Tank, in = 50 in	

1. Calculate total chlorine in container.

$$\begin{aligned}\text{Total Chlorine, lbs} &= (\text{Chlorine, lbs/gal bleach})(\text{Bleach, gal})\\ &= (0.44\ \text{lbs/gal})(10\ \text{gal})\\ &= 4.4\ \text{lbs}\end{aligned}$$

2. Determine the chlorine used in pounds.

$$\begin{aligned}\text{Chlorine Used, lbs} &= \frac{(\text{Total Chlorine, lbs})(\text{Chlorine Used, in})}{\text{Depth of Tank, in}}\\ &= \frac{(4.4\ \text{lbs})(10\ \text{in})}{50\ \text{in}}\\ &= 0.88\ \text{lbs}\end{aligned}$$

3. Estimate the average chlorine dose in mg/*L*.

$$\begin{aligned}\text{Average Chlorine, Dose, mg/}L &= \frac{(\text{Chlorine Used, lbs})(1{,}000{,}000)}{(\text{Water Treated, gal})(1\ \text{M})(8.34\ \text{lbs/gal})}\\ &= \frac{(0.88\ \text{lbs})(1{,}000{,}000)}{(100{,}000\ \text{gal})(1\ \text{M})(8.34\ \text{lbs/gal})}\\ &= 1.1\ \text{mg/}L\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 218.

4.5A List the various methods used to disinfect domestic water supplies.

4.5B List the common forms of chlorine available to disinfect water supplies.

4.5C What does a chlorinator do?

4.5D What substances found in water react with and consume chlorine?

4.5E List the two types of chlorine residuals that can be measured with test kits.

4.5F Calculate the desired free chlorine residual for a water with a pH of 7.6 when the water is 5°C. The contact time is 25 minutes.

End of Lesson 1 of 2 Lessons
on
SMALL WATER TREATMENT PLANTS

DISCUSSION AND REVIEW QUESTIONS

Chapter 4. SMALL WATER TREATMENT PLANTS

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

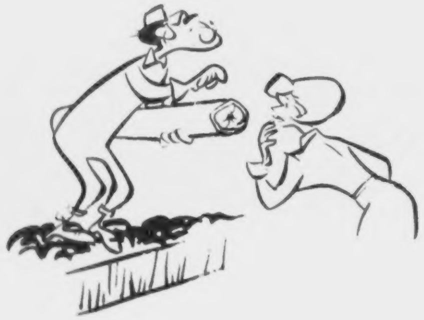
1. Why do small water treatment plants often not perform satisfactorily?
2. Why may prechlorination be recommended?
3. What happens if the coagulant dosage is either too high or too low?
4. If the cause of turbidity increases in the treated water is a change in the source water, what could have caused changes in the source water?
5. What would you do if a flocculation process is not satisfactorily producing a floc that settles quickly and clarifies the water effectively?
6. List the factors that influence the performance of a settling basin.
7. Successful operation of filters at high rates requires what conditions?
8. If a filter is not performing satisfactorily, what would you do?
9. Why do small water treatment plants frequently use hypochlorite forms instead of chlorine gas?
10. Effectiveness of disinfection of water with chlorine depends on what factors?
11. How would you determine if the chlorinator setting is high enough?
12. How would you try to prevent chlorinator failures?

CHAPTER 4. SMALL WATER TREATMENT PLANTS

(Lesson 2 of 2 Lessons)

4.6 CORROSION CONTROL

Water is frequently corrosive to materials that it contacts, especially metal. Corrosion of metal is an *ELECTROCHEMICAL REACTION*[21] in which materials are dissolved into the water. This process of corrosion may work slowly but over the extended periods of time involved in water systems, it can be very important. Pipelines, storage tanks, and other structures can be seriously damaged by corrosion. Corrosion can decrease the flow capacity of pipelines and significantly increase pumping costs. Also, the quality of water delivered to consumers can be seriously affected by corrosion in the system. Corrosion can cause the water to become discolored or turbid from suspended rust particles



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[21] *Electrochemical Reaction. Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action). In corrosion, a chemical reaction is accompanied by the flow of electrons through a metallic path. The electron flow may come from an external force and cause the reaction, such as electrolysis caused by a D.C. (direct current) electric railway, or the electron flow may be caused by a chemical reaction as in the galvanic action of a flashlight dry cell.*

and the water may have an unpleasant taste. The water may also contain harmful concentrations of metals like copper, zinc and lead. Therefore, corrosion control measures are well worthwhile because water system parts that have been damaged by corrosion are very expensive to replace or repair and corrosion can cause the water quality to become unacceptable to consumers.

There are two general methods often used to control corrosion. One method is to use construction materials that resist corrosion. For instance, iron or steel pipe can be lined with cement or coated with coal tar enamel to protect the pipe. A zinc galvanized coating can be applied to small iron plumbing pipes. Copper pipes resist corrosion in most cases and plastic pipes are completely free of corrosion.

The second method of controlling corrosion is to treat the water with chemicals to make it noncorrosive. The chemicals sometimes used include lime, soda ash, caustic soda, sodium silicate and polyphosphates. Chemical treatment of the water is of limited effectiveness and should be considered only as a supplement to the use of materials that are naturally resistant to corrosion.

The corrosion control chemicals are usually dissolved in water and fed in a solution form. Lime and soda ash can also be fed in the dry granular or powder forms. The dosage of lime, soda ash or caustic soda is set to adjust the pH of the treated water so a thin film of calcium carbonate is deposited on the pipe surface. This thin coating prevents corrosion of the pipe. Usually the proper pH is in the range of 8.0 to 9.0.

One method to determine the proper pH is to calculate the Langelier Index which takes into account the various factors affecting the corrosiveness of water. The formula and procedures to calculate the Langelier Index are given in Chapter 8, "Corrosion Control," *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals. The dosage of silicate or phosphate is usually determined from past experience with similar types of water. Normally a dosage of several milligrams per liter is necessary. Do not use phosphate compounds if the system has open reservoirs because the phosphate may encourage excessive algae growths.

Corrosion control chemicals are the last ones to be applied after all other treatment has been accomplished. The reason is that the pH required for successful coagulation and disinfection is much lower than the pH required to make the water noncorrosive. Also, a coating of calcium carbonate on the filter media should be avoided because it interferes with effective filtration. The operator must understand that any lime or soda ash applied with the alum to improve coagulation has a minimum impact in controlling corrosion. These materials are all consumed in the chemical reactions that occur during coagulation. Therefore, to make the water noncorrosive, additional lime, soda ash or caustic soda must be added in the final stage of treatment.

LIME
CAUSTIC SODA
SODA ASH

The pH of the water is frequently used as a day-to-day indicator of the corrosive nature of the water. Water of higher pH is normally less corrosive than water of a lower pH. However, because of the many factors that can affect corrosion, the pH measurement is not totally reliable. The best method of monitoring corrosion is to examine specimens of the actual pipeline material or the surface of the structure involved. This inspection is easy if sections of pipe can be removed periodically. Alternatively, small specimens of the pipeline material can be mounted in the flowing water and periodically removed for inspection.

Waters with a low pH are very aggressive and can dissolve concrete and asbestos cement pipe. Increasing the pH of the water by the use of chemicals can reduce the rate of deterioration of the materials.

For additional information on corrosion control, see Chapter 8, "Corrosion Control," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 219.

4.6A List the two general methods of controlling corrosion.

4.6B What is the best method of monitoring corrosion in a water main?

4.7 SOLIDS-CONTACT CLARIFICATION

by J.T. Monscvitz

4.70 Process Description

Solids-contact clarifiers (Figures 4.18 and 4.19) go by several names, which may be used interchangeably: solids-contact clarifiers, up-flow clarifiers, reactivators, and precipitators. The basic principles of operation are all the same, even though various manufacturers use different terms to describe how the mechanism may work.

The solids-contact units first got their start in the Midwest as a means of handling water softening problems which generated large amounts of sludge. Some manufacturers wished to call the sludge a slurry, but to most all water plant operators the settled material from coagulation or softening is simply called sludge.

From the early beginnings of the softening process, it soon became obvious that the solids-contact units could be used to remove turbidity from drinking water. A great number of up-flow clarifiers have found their way into water treatment plants as a means for turbidity removal in a very compact, single unit process. However, the internal mechanism consists of three distinct unit processes that function identically to any conventional coagulation-flocculation-sedimentation process chain.

A spearheading factor in the use of the solids contact, and no doubt how it derived its name, is based on a simple principle operators have used for many years very successfully. This principle is the re-cycling of settled slurry or sludge into coagulation and flocculation processes and taking advantage of mass action. Many years ago, some operators found that returning a portion of the previously settled sludge provided an excellent coagulation aid to the flocculation process.

In any event, if you will consider that the solids contact unit is basically coagulation and flocculation based upon the

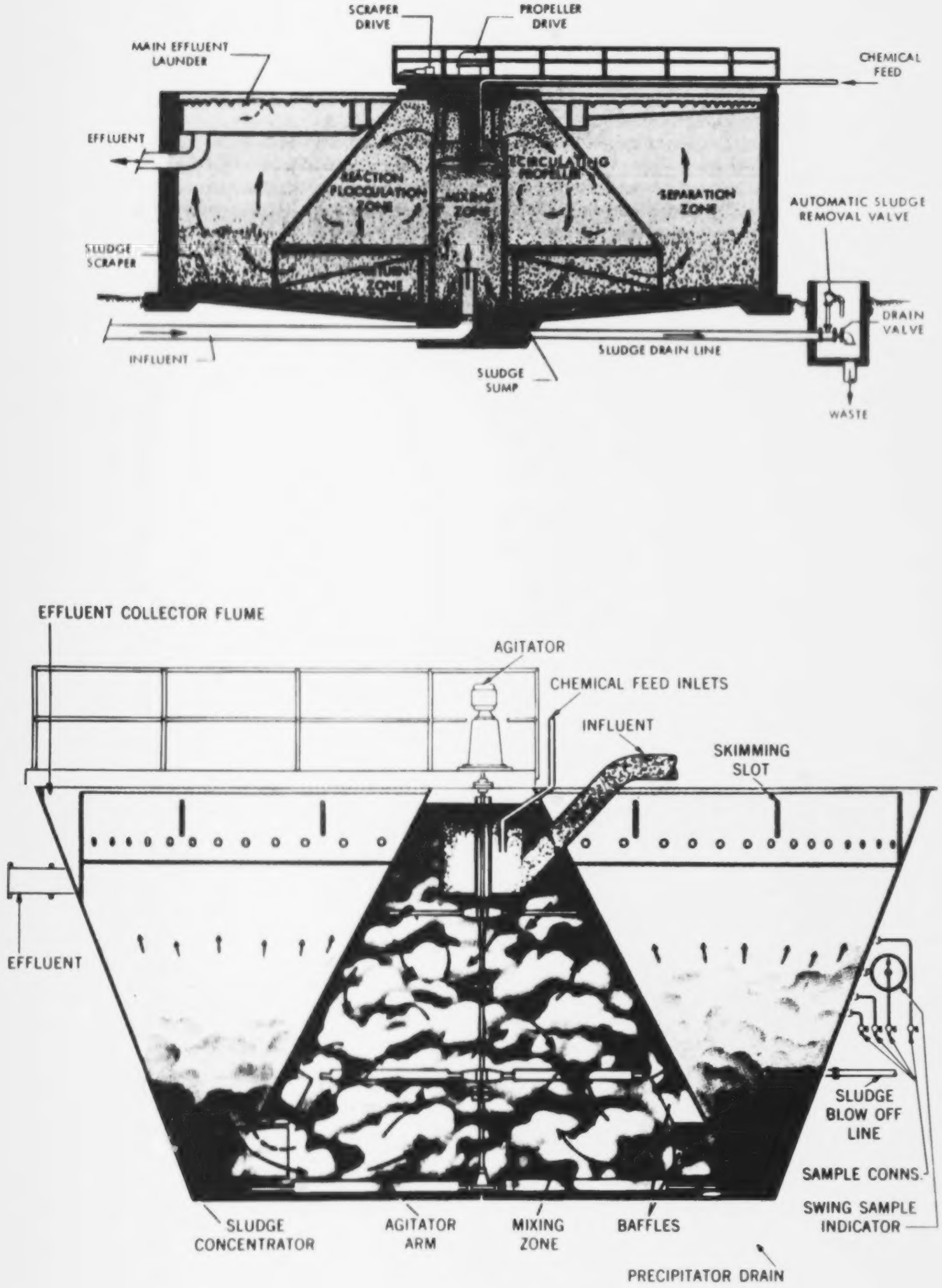
SCRAPER DRIVE
PROPELLER DRIVE
MAIN EFFLUENT LAUNDER
CHEMICAL FEED
EFFLUENT
REACTION FLOCCULATION ZONE
MIXING ZONE
RECIRCULATING PROPELLER
SEPARATION ZONE
AUTOMATIC SLUDGE REMOVAL VALVE
SLUDGE SCRAPER
ZONE
DRAIN VALVE
INFLUENT
SLUDGE DRAIN LINE
SLUDGE SUMP
WASTE
EFFLUENT COLLECTOR FLUME
AGITATOR
CHEMICAL FEED INLETS
INFLUENT
SKIMMING SLOT
EFFLUENT
SLUDGE BLOW OFF LINE
SAMPLE CONNS.
SWING SAMPLE INDICATOR
SLUDGE CONCENTRATOR
AGITATOR ARM
MIXING ZONE
BAFFLES
PRECIPITATOR DRAIN

Fig. 4.18 Solids-contact clarifiers

Permission of Permutit Company

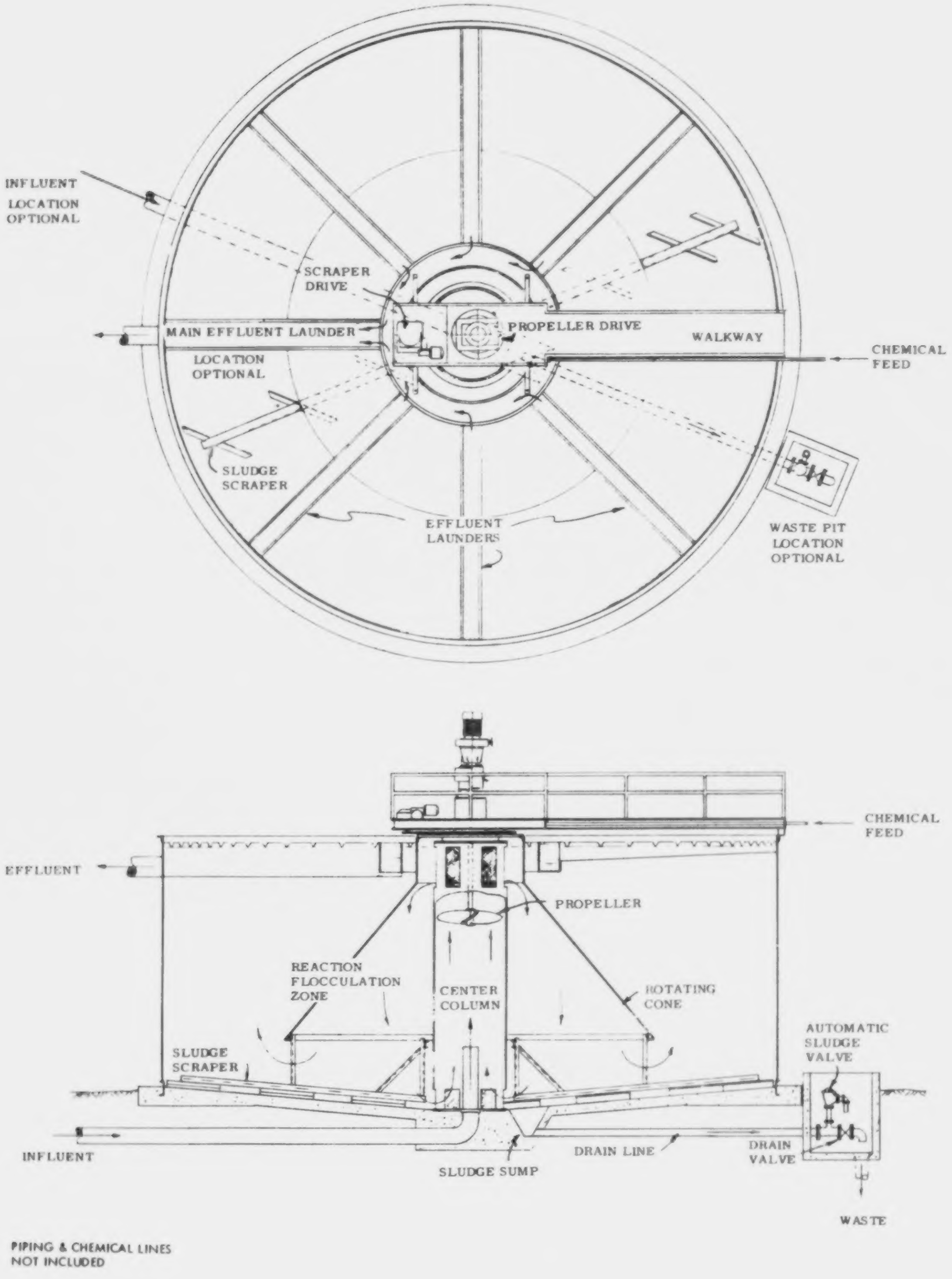
INFLUENT
LOCATION OPTIONAL
SCRAPER DRIVE
MAIN EFFLUENT LAUNDER
PROPELLER DRIVE
WALKWAY
CHEMICAL FEED
LOCATION OPTIONAL
SLUDGE SCRAPER
EFFLUENT LAUNDERS
WASTE PIT LOCATION OPTIONAL
CHEMICAL FEED
EFFLUENT
PROPELLER
REACTION FLOCCULATION ZONE
CENTER COLUMN
ROTATING CONE
AUTOMATIC SLUDGE VALVE
SLUDGE SCRAPER
INFLUENT
SLUDGE SUMP
DRAIN LINE
DRAIN VALVE
WASTE
PIPING & CHEMICAL LINES NOT INCLUDED

Fig. 4.19 Plan and section views of a solids-contact clarifier

(Permission of General Filter)

principle of re-cycling sludge, you will have a basic understanding of the solids-contact reactors, and perhaps "reactors" are a better description of the solids-contact units.

In the normal use of the solids-contact units for removal of turbidity, there are several outstanding advantages. Conversely, there are some disadvantages, but in the overall scheme the advantages may outweigh the disadvantages. You simply have one reaction unit to contend with, which can greatly reduce capital and maintenance costs because of the absence of independent chambers for flash mixing-coagulation-flocculation and sedimentation. The disadvantage is that you must be more competent, have an understanding of these processes, and be able to conceptually visualize all of these processes occurring in a small chamber or clarifier at the same time. Herein lies the problem confronting water plant operators when first faced with the operation of the up-flow clarifier. Operators often have trouble visualizing that all of these processes are occurring at the same time. Operators can become discouraged, blame the problem on the engineer who designed the plant, and wonder why a process that was meant to be simple becomes so complex to handle on a daily basis.

Often the initial judgment for the placing of a solids-contact unit into a treatment plant has its own limitations. Understanding the process will greatly enhance the operator's ability to cope with these problems. Also, understanding the process will not cause the operator to become upset because certain problems associated with the solids-contact units can and do occur.

A tremendous advantage in the use of the solids-contact units is the ability to accumulate slurry (sludge blanket), which can be taken advantage of during periods of severe taste and odor problems. By proper control of the slurry, you can develop a large amount of activated carbon in the slurry and take advantage of its *ABSORPTIVE*[22] characteristics. Similarly, when coagulation fails because of increased algal activities, you can take advantage of the slurry accumulation to carry the plant through the severe periods of the day when the chemicals will fail to react properly because of changes in the pH, alkalinity, carbonate, and dissolved oxygen. In the conventional plant, the operator cannot respond to this type of breakdown in the coagulation process as well as the operator can with a solids-contact unit. Once you decide that the algal activities are causing the problem (readily checked by pH and DO) you can — during the good periods of the day — increase the amount of slurry available and remove it during periods when the coagulation process is not functioning well. In doing so skillfully, you can well maintain a quality effluent from the solids-contact unit.

The point most often criticized concerning solids-contact units is their instability during rapid changes. Three factors must be considered.

1. Flow (through-put) rate and its rate of change,
2. Severe fluctuations in the turbidity level, and
3. Rapid changes in temperature.

Treating each of the above independently, the solids-contact unit is most unstable during rapid changes in the flow rate. The operator should identify and keep in mind the design flow for which the unit was constructed. The design flow may be converted to an *OVERFLOW RATE*[23] which may be expressed as the rise rate (inches per minute or feet per minute). For each rise rate there will be an optimum (best) slurry to be maintained within the unit. A change in rising will increase the depth of the slurry without increasing its volume or density. Conversely, a decrease in flow rate will reduce the level of slurry without changing its volume.

Simple tests of changing flow rates can be performed to observe this phenomenon and clearly show the operator errors and/or predict the problem during changes. The level of slurries can be identified by sampling taps which are placed at various depths of the wall of the solids-contact reactor. The sampling taps should penetrate the wall and extend into the slurry zone. Frequently to accomplish this, you may have to make additions to the sampling pipes which were initially installed with the unit. However, by measuring and observing these depths, you can rapidly determine the rise or fall of the slurry and may have to adjust the recirculation device to accommodate these changes and/or place a more rigorous control on the rate of change of the flow. This, of course, is easy in a gravity flow system, when the water demands are moderate, and the change in flow can be performed slowly. However, in pressure systems, responding to rapid changes in demands or placing pumps into service at full capacity can easily upset an up-flow clarifier immediately. By observing the sampling taps, you can witness the crisis occurring and be next to helpless to respond. You will see the slurry rapidly rising in the settling zone, approach the overflow weirs, and spill onto the filters with a complete and total breakdown of the plant process.

The next factor which can upset solids-contact clarifiers is severe turbidity changes. This phenomena is not peculiar to flow rates, but is extremely troublesome when it occurs. The answer to the turbidity change is one of alertness on behalf of the operator. You must accurately forecast when the turbidity may arrive at the reaction zone and be prepared to cope with the turbidity change with the proper chemical dosage. You should attempt to forecast turbidity increases and increase the chemical dosage used prior to the arrival of turbidity and therefore have the unit in a mode in which the turbidity can be handled successfully. More will be discussed later concerning control of slurry and its influence on this process.

A very significant item is that of temperature. Changes in temperature will cause changes in density of water, which influences the particle settling rate. Conversely, simple heating by the sun on the wall of the tank or on the flocculant particles within the container will cause a certain amount of carryover to occur. Anyone being first initiated to a solids-contact unit may tend to become upset and over-react because of the potential carryover problem. This phenomenon is not one of real concern because as the position of the sun changes, the convection currents change and where a cloud of flocculant particles appear they soon will disap-

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[22] *Absorption (ab-SORP-shun). Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).*

[23] *Overflow Rate. One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called* SURFACE LOADING.

$$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

If we divide the overflow rate by 7.48 gallons per cubic foot and also divide by 1440 minutes per day, we will have converted the overflow rate to a rise rate in feet per minute.

pear and occur somewhere else. There is no real need to control this phenomenon if the overall settled turbidity meets your objective. So long as the major portion of the sludge blanket lies in the settling zone, the few clouds of flocculant particles (billowing-like clouds) really do not significantly harm the operation of the unit or the quality of the water produced. However, in an extremely cold water, you must consider increasing the chemical dosages by the use of polymers, activated silica, powdered calcium carbonate, or some other weighting agents that aid sedimentation and not coagulation.

Changing temperature and flow rates may make it impossible to control process upsets. The slurry rises to the weirs and is carried over onto the filters. When this happens you must reduce the flow rate. If possible, weighting agents should be used before changing flow rates in cold water. The use of weighting agents may cause problems with the slurry resulting in changes in recirculation rates. However, too high a recirculation rate may also cause the slurry to overflow onto the filters. During a change in temperature (cold water) you must be careful in changing the flow rate.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 219.

4.7A List two advantages of solids-contact units.

4.7B How can the level of the slurry or sludge blanket be determined in solids-contact units?

4.7C What should be done when a rapid change in turbidity is expected?

4.71 Fundamentals of Operation

There are three fundamental principles that you must be aware of in order to make a solids-contact unit function properly. These are:

1. Chemical dosage,
2. Recirculation, and
3. Sludge control.

All three of these principles are interrelated and frequently you may have trouble distinguishing which one may be the root of a problem you are encountering. However, if you will use the following analytical techniques, you should be able to separate the three fundamentals into separate groups and diagnose the cause of the upset. This is not to say that if you have one problem, it may not co-exist with the other two.

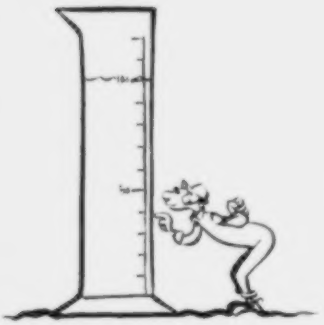
First, let's consider chemical dosage. As in conventional treatment plants, proper consideration must be given to chemical dosage, otherwise the entire system of solids-contact clarification will collapse. Therefore, you must be aware that there must be sufficient alkalinity in the raw water to react with the coagulant. Assuming for practical purposes the coagulant used is aluminum sulfate, for every mg/*L* of alum added, it will require 0.45 mg/*L* of bicarbonate alkalinity. To drive the chemical reaction sufficiently to the right (that is to say, for precipitation to occur), there should be an excess of 20 mg/*L* of alkalinity present. You may have to add sodium hydroxide (caustic soda), calcium hydroxide (lime), or sodium carbonate (soda ash) to cause sufficient alkalinity to be present. For example, if there was only 20 mg/*L* of natural alkalinity present, for every mg/*L* of alum added, you should add 0.35 mg/*L* of lime if calcium hydroxide was being used.

All of this information can be verified by jar testing, which is fundamental in determining proper coagulation by chemical dosing. You should never attempt to make changes in solids-contact unit operation without first determining the proper chemical dosage through jar testing. For most solids-contact units, the chemical dosages that produce floc which gives the lowest turbidity within a five-minute settling period after stopping the jar tester, should be selected as the unit's dosage. Using the above criteria, the operator now can set the chemical feeders to dose the raw water entering the solids-contact unit.

The next principle is one of recirculation. Here most often the plant operator is misled by intuitive judgment. Recirculation is established by the speed of the impeller, turbine, pumping unit, or by air injection. Anyone of the above recirculation devices causes the slurry to recirculate through the coagulation (reaction) zone passing into the settling zone with a portion of the slurry being returned to the coagulation zone. If you can visualize a brown paper bag grasped in your hand, blown up with air, and sqeezed slightly from the bottom to expand that portion of the bag, this should give you a picture as to how the slurry should appear in the contact unit. In principle, you are attempting to chemically dose the raw water when it enters the reaction zone and is mixed with the recirculated sludge — coagulation and flocculation occurring in the reaction zone after which the water along with sludge passes into the settling zone.

At this point in the reaction, approximately one liter of water should rise and one liter as slurry should return into the reaction zone. In order to sort the principles out, you should keep a log of the speed (RPM) of the recirculation device. If air is used for mixing, then the cubic feet of air applied per minute should be recorded. A point to remember is that there is a direct relationship between the percentage of slurry present and the speed at which the mixing device is travelling. Also, there are conditions within the reactor that the operator must observe.

The first step here is to determine the percentage of slurry present in the reaction zone. This can be performed by what might be called a volume over volume (V/V) test. The test procedure used is to take a 100 m*L* graduated cylinder, select a sample from the reaction zone, let it sit for five minutes and determine the volume of slurry accumulated (m*L*). At the same time you should observe the clarity of the supernatant (settled water) that remains in the graduated cylinder. The clarity of the water above the slurry (the supernatant) will indicate to you how well the chemical reaction is proceeding. The percentage of accumulated solids will indicate whether a proper amount of slurry is in the reaction zone. Customarily such reactors require 5 to 20 percent solids, or a higher percentage in the graduated cylinder at the end of a five to ten-minute settling period.



Through recordkeeping and experience, you will find an optimum percentage of solids to maintain. You should perform the above analyses hourly and more frequently when the raw water quality is undergoing change. Accurate records must be kept.

The final step in control of the solids-contact unit is the removal of sludge which has accumulated on the bottom of the clarifier (settling zone). There are several means of sludge collection; some methods are located in areas of clarifiers that hold the sludge and are controlled by opening and closing recirculation gates. Others have scrapers that collect the sludge and move it to a discharge sump. In both cases the sludge is removed by hydraulic means (water pressure) through a control valve. The sludge removal mechanisms are generally on a timer, which operates periodically for a time duration set by the operator. The means of making this judgment is quite simple. Once again, through the use of a graduated cylinder, a sample is taken from the sludge discharge line. The sludge being discharged should be 90 to 98 percent solids in a V/V test, as indicated above. A five to ten minute period should be sufficient to make this determination. Slurries or sludge weaker than 90 percent means that the operator is discharging a considerable amount of water and not leaving enough sludge to be recirculated into the reaction zone. If the percentage is considerably greater, then there may be too much sludge accumulated and the recirculation device may be becoming overloaded with too much return slurry.

If you will visualize the above reactions, you can see that with increased speed of the recirculation device, a larger amount of slurry can be retained in the unit. At the same time if this amount becomes too great, it may cause the sludge to rise and ultimately spill over the effluent weirs with the treated water. If the recirculation rate is too low, the solids may settle too soon and without sufficient recirculation will not return to the reaction zone. The absence of solids in the reaction zone causes improper coagulation. The net result is a failure of the total solids-contact system.

Considering the above principles and provided with some experience, you should be able to determine an optimum amount of slurry to be present that will satisfy a given recirculation rate, coupled with proper chemical dosage, and a sufficient percentage of solids for recycling. You should always be aware of the amount of solids in the reaction zone and, based upon practical experience, know approximately the percentage required. Some of the obvious difficulties in this judgment will occur as the raw water turbidity changes. For instance, in muddy streams carrying silt, sedimentation may occur very rapidly, thus requiring increased circulation rates to maintain sufficient slurry in the reaction zone even with proper chemical dosage, and also will require greater sludge removal rates. As the raw water turbidity becomes lighter, the increased circulation rate may cause the slurry blanket to rise to an uncontrolled depth in the settling zone, as will removing too much sludge. All of these problems are readily observed in the V/V test for solids determination in the reaction zone; also, this is cause for increased observations of the V/V during water quality changes.

Another problem may be caused by cold water when the recirculation rate may be too high for the densities of the particles present, suggesting that a set of recirculation speeds for warm-weather operation may be entirely different from those used during cold weather. As a remedy, the operator may select a nonionic polymer as a weighting agent to increase the settling rate in cold waters. Other alternative chemicals are powdered calcium carbonate or the use of activated silica. A note of caution in chemical dosage determination, is that the reactions in the jar tester should be reasonably rapid to assure comparable reactions within the solids-contact unit.

Another important point when determining chemical dosage for a solids-contact unit is that a specific set of jar test guidelines will be needed. For example, you should determine the volume of the reaction zone and the period of detention of the raw water in that reaction zone. This, along with knowledge of the speed of the recirculation device, should allow you to determine the detention time and flocculator speed in the jar tester.

In the real world, this means if the flow rate of the solids-contact unit is ten minutes in the reaction zone and the speed is two feet per second (0.6 m/sec), then the jar tester mixer should turn at a speed equal to two feet per second with a coagulation period of ten minutes. You should duplicate in the jar tester, as nearly as possible, those conditions of chemical dosage, detention period, and mixing speeds that occur in the solids-contact unit. Using these guidelines, you should be able to approach approximate real-world conditions in the laboratory and better optimize chemical dosages.

4.72 Maintenance

Solids-contact units, like all waterworks equipment, require at least a minimum of maintenance. The primary consideration is the recirculating device which needs regular inspection concerning the belt drive, gear boxes, and lubrication. Also if the unit has a sludge collector, then its drive and gear boxes require the same attention. The units should be inspected daily and lubricated in accordance with manufacturer's recommendations. A similar statement is applicable to the sludge collecting devices. Also, periodically the contact unit may need to be drained and the sludge collectors inspected for wear and corrosion.

Sludge collector devices are usually constructed of steel within a concrete container. Thus, there is a need to inspect the *CATHODIC PROTECTION*[24] system if one is provided with the unit. Weekly readings should be kept concerning the amperes and voltage supply. Changes in these readings should call for inspection of the devices and corrections made once the defects have been identified.

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[24] *Cathodic Protection (ca-THOD-ick). A system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic and concentrates corrosion on auxiliary anodic parts used for the purpose of corrosion instead of the structure.*

For additional information on Solids-Contact Units, see Section 5.243, "Arithmetic for Solids-Contact Clarification," page 174, of *WATER TREATMENT PLANT OPERATION*, Volume I, of this series of manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 219.

4.7D How is the proper chemical dose selected when operating a solids-contact unit?

4.7E List the devices that may be used to provide recirculation in a solids-contact unit.

4.7F How is the percentage of slurry present in the reaction zone determined?

4.8 IRON AND MANGANESE CONTROL

Excessive iron and manganese in drinking waters are objectionable because they stain clothes and encourage the growth of iron bacteria. These bacteria form thick slimes on the walls of pipes. When these slimes break away from the pipes, the iron causes a rust colored water and the manganese produces black particles. These slimes also impart foul tastes and odors to the water. For these reasons, iron should not exceed 0.3 mg/*L* and manganese 0.05 mg/*L* in drinking waters.

If a new well is drilled and excessive amounts of iron or manganese are discovered, the best solution may be to drill a new well. Consult with well drillers in the area and also collect and analyze samples from nearby wells. Discuss your situation with the state agency responsible for the regulation of well drilling. Sometimes a new well is cheaper and a lot less trouble than trying to control or remove iron and manganese. In many areas a new well will produce water with just as much iron and manganese. Surface waters also may contain excessive amounts of iron and manganese, especially when you have small, shallow reservoirs. Usually manganese is more of a problem than iron.

If the water contains less than 1.0 mg/*L* iron and less than 0.3 mg/*L* manganese, the use of polyphosphates followed by chlorination can be effective and inexpensive. Any of the three polyphosphates (pyrophosphate, tripolyphosphate, or metaphosphate) can be used, but sodium metaphosphate usually requires a lower dosage than the others.

To determine the best polyphosphate, prepare a series of samples with varying concentrations of polyphosphate. Stir to assure that the polyphosphate is well mixed. Add enough chlorine to produce a chlorine residual of 0.25 mg/*L* after a five-minute contact time period. Be sure the samples are well mixed. Observe the samples daily against a white background, recording the amount of discoloration. The proper polyphosphate dose is the lowest dose that delays noticeable discoloration for a period of four days.

The addition of either chlorine or potassium permanganate will oxidize iron and manganese to insoluble precipitates which can be removed by filtration. Chlorine will oxidize manganese to insoluble manganese dioxide and iron to insoluble ferric hydroxide. The higher the chlorine residual, the faster the reaction goes. Some plants add chlorine to produce a residual of from 5 to 10 mg chlorine per liter (*SUPERCHLORINATION*[25]). The insoluble precipitates are removed by filtration. The water is dechlorinated by the use of reducing agents such as sulfur dioxide (SO_2), sodium bisulfite ($NaHSO_3$), and sodium sulfite (Na_2SO_3). Bisulfite is commonly used because it is cheaper and more stable than sulfite. A chlorine residual must be maintained in the treated water throughout the distribution system.

Potassium permanganate can be used to accomplish the same result as chlorine. The dose must be exact. Too little permanganate will not oxidize all of the manganese for removal and too much will allow permanganate to enter the distribution system and cause a pink color.

Filtration is used to remove the insoluble precipitates. Sometimes a *GREENSAND*[26] is used which oxidizes iron and manganese to their insoluble oxides. The greensand is capable of both oxidation and filtration. The greensand may be regenerated by the use of potassium permanganate.

BLACK SPOTS
Lime-Soda ash
PINK COLOR
RUST COLORED
GREENSAND

Iron can be oxidized by *AERATING*[27] water to form insoluble ferric hydroxide. The higher the pH, the faster the reaction. The oxidation of manganese by aeration is so slow that this process is not used on waters with high manganese concentrations. Aeration is achieved by spraying water into the air, allowing the water to flow over steps or passing the water over coke trays. After aeration, adequate holding time in a retention basin is required for the oxidation reactions to take place. After the ferric hydroxide is formed, the insoluble precipitate is removed by sedimentation and filtration, or by filtration alone. The main advantage of this method is that no chemicals are required. For information on the operation of pressure filters, see Section 4.4, "Filtration."

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[25] *Superchlorination. Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.*

[26] ***Greensand.** A sand which looks like ordinary filter sand except that it is green in color. This sand is a natural ion exchange mineral which is capable of softening water.*

[27] ***Aeration (air-A-shun).** The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.*

Ion exchange can be used to remove both iron and manganese if the water to be treated contains no dissolved oxygen. Usually groundwaters do not contain dissolved oxygen. If dissolved oxygen is present, the exchange resin becomes fouled with iron rust or manganese dioxide. Cleaning the resin is expensive. The procedures for operating and maintaining ion exchange units are outlined in the next section on softening.

For additional information and details on the control of iron and manganese, see Chapter 12, "Iron and Manganese Control," in *WATER TREATMENT PLANT OPERATION*, Volume II, of this series of manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 219.

4.8A Why are excessive amounts of iron and manganese in drinking waters objectionable?

4.8B Why is greensand sometimes used to treat iron and manganese?

4.8C What is the main advantage of treating iron by aerating water?

4.8D Why must there be no dissolved oxygen present when using ion exchange units to remove iron and manganese?

4.9 SOFTENING

4.90 Lime-Soda Ash Softening

The exact procedures used to soften water by chemical precipitation using the lime-soda ash process will depend on the hardness and other chemical characteristics of the water being treated. A series of jar tests are commonly used to determine optimum dosages. In many cases, the feed rates determined by jar tests do not produce the exact same results in an actual plant. This is because of differences in water temperature, size and shape of jar as compared with plant basins, mixing equipment, and influence of coagulant (a heavy alum feed will neutralize more of the lime). You must remember that jar test results are a starting point. You may have to make additional adjustments to the chemical feeders in your plant based on actual analyses of the treated water.

Let's set up some jar tests to determine the optimum dosages for lime or lime-soda treatment to remove hardness from well water. To get started, add 10.0 grams of lime to a one liter container and fill to the one-liter mark with distilled water. Thoroughly mix this stock solution in order to dissolve all of the lime. One *mL* of this solution in a liter of water is the same as a lime dosage of ten mg/*L* (0.5 *mL* in 500 *mL* is still the same as a ten mg/*L* lime dose).

Set up a series of hardness tests by adding 5.0 *mL*, 10.0 *mL*, 15.0 *mL*, 20.0 *mL*, 25.0 *mL*, 30.0 *mL*, 35.0 *mL* and 40.0 *mL* to one liter (1000 *mL*) containers or jars. Fill the containers to the 1000 *mL* mark with the water being tested. Mix thoroughly, allow the precipitate to settle and measure the hardness remaining in the water above the precipitate. A plot of the hardness remaining against the lime dosage will often reveal the optimum dosage. See Figures 4.20, 4.21 and 4.22.[28]

Examination of Figures 4.20, 4.21 and 4.22 reveals that the water of all three cities responded differently to the increasing lime dosage. City 1 (Figure 4.20) should be providing a lime dosage of 100 mg/*L*. The cost of increasing the dosage to 150 mg/*L* is not worth the slight reduction in hardness from 110 to 100 mg/*L* as $CaCO_3$. Note that an overfeed of lime will actually increase the hardness.

City 2 (Figure 4.21) should be providing a lime dose of 200 mg/*L*. A dose of 300 mg/*L* will reduce hardness, but the increase in lime costs are too great. City 3 (Figure 4.22) should be dosing lime between 200 and 250 mg/*L*. Note that the greater the lime dose, the less the hardness, but the greater the quantities of sludge that must be handled and disposed of.

If lime added to the water does not remove sufficient hardness, select the optimum lime dose and then add varying amounts of soda ash. From Figure 4.22, we found that the optimum lime dose was 200 mg/*L* (300 mg/*L* would have reduced the hardness only slightly more). Let's take six one-liter containers and add 20 *mL* of our lime stock solution (a dosage of 200 mg/*L*). Prepare a stock solution of soda ash similar to our lime solution. Add 10 grams of soda ash to a one-liter container, fill with distilled water and mix thoroughly. Add zero, 2.5 *mL* (2.5 mg/*L* dose), 5 *mL*, 7.5 *mL*, 10 *mL*, 12.5 *mL* and 15 *mL*. Mix thoroughly, allow the precipitate to settle and measure the hardness remaining in the water above the precipitate. A plot of hardness remaining against the soda ash dosage will reveal the desired dosage. We would like the final hardness to be in the 80 to 90 mg/*L* as $CaCO_3$ range.

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[28] *These figures were adapted from an article titled, "Use of Softening Curve for Lime Dosage Control," by Michael D. Curry, P.E., which appeared in THE DIGESTER/OVER THE SPILLWAY, published by the Illinois Environmental Protection Agency.*

To select the optimum doses of lime and soda ash, consider the items discussed below.

1. Optimum dosage of lime was based on increments of 50 mg/*L*. You should refine this test by trying at least two-10 mg/*L* increments above and below the optimum dose. From Figure 4.20 we found that 100 mg/*L* was the optimum dose. Try lime doses of 80, 90, 100, 110 and 120 mg/*L*.
2. Optimum dosage of soda ash can be refined by trying similar increments also.
3. Try slightly increasing the actual lime dose in your plant to see if there is any decrease in the remaining hardness. Is the decrease in hardness worth the increase in lime costs?
4. Try slightly increasing and decreasing both lime and soda ash dosages at your plant one at a time, and evaluate the results.
5. If you are treating well water or a water of constant quality, all you have to do to maintain proper treatment is to make minor adjustments to keep the system fine tuned.
6. If you are treating water from a lake or a river and the water quality (including temperature) changes, you'll have to repeat these procedures whenever the source water quality changes. Water quality changes of concern include raw water hardness, alkalinity, turbidity and temperature.
7. REMEMBER, you do not want to produce water of zero hardness. If you can get the hardness down to around 80 to 90 mg/*L*, that usually will be low enough for most domestic consumers.

After the chemicals have been mixed, the precipitates are allowed to settle out in some type of settling or sedimentation basin. Sludges from the lime or lime-soda softening processes are usually disposed of in sanitary landfills.

The next process is recarbonation. This process introduces carbon dioxide into the treated water to lower the pH and stabilize the water to prevent the precipitation of carbonate compounds on the filter media, in the clear well, and in the pipes in the distribution system. The pH to which the water should be lowered is determined by the Marble test. See Chapter 21, "Advanced Laboratory Procedures," in *WATER TREATMENT PLANT OPERATION*, Volume II, of this series of manuals for details on how to perform the Marble test. For information on how to operate gravity filters, see Section 4.4, "Filtration."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 219.

4.9A The procedures for softening water by chemical precipitation using the lime-soda ash process depend on what factors?

4.9B If lime added to water does not reduce the hardness of a water sufficiently, what would you do?

4.9C Why should softening waters from the lime-soda ash process pass through a recarbonation process before filtration?

4.91 Ion Exchange Softening

Ion exchange water softening is a process in which the hardness-causing ions (mainly calcium and magnesium) are exchanged (or traded) for sodium ions by passing the water through an ion exchange media. *ZEOLITE*[29] softening refers to sodium ion exchangers and will mean the same as ion exchange in this manual.

There are three basic types of ion exchangers in use today. One type is an upflow unit in which the water enters from the bottom and flows up through the resin exchange bed and out the top. Another type operates like a gravity sand filter. The water enters at the top, flows down through the softening media and out the bottom. The most common type is the pressure down-flow ion exchange softener.

Try to operate your ion exchange unit at design flows or less. Measure the hardness of the water entering the unit and the hardness of the water leaving (there should be zero hardness leaving). Monitoring influent hardness is very important, especially for surface waters. Zeolite softeners are designed to remove a specified amount of hardness before they require regeneration. See Example 14.

If design flows through a zeolite softener cannot be achieved or if the head loss through the softener becomes greater than normal, the resin may need backwashing. To backwash an ion exchange softener, take the unit out of service and reverse the flow pattern through the unit. The purpose of backwashing is to expand and clean the media particles, thus freeing any material such as iron and manganese that might have been removed during the softening stage.

Slowly allow the backwash water to enter the softener and gradually increase the backwash rate to the design flow. Periodically during the backwash process, catch a sample of effluent with a glass beaker. A trace amount of media should cause no alarm, but a steady loss of media could indicate a

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[29] *Zeolite. A type of ion exchange material used to soften water. Natural zeolites are siliceous compounds (made of silica) which remove calcium and magnesium from hard water and replace them with sodium. Synthetic or organic zeolites are ion exchange materials which remove calcium or magnesium and replace them with either sodium or hydrogen.*

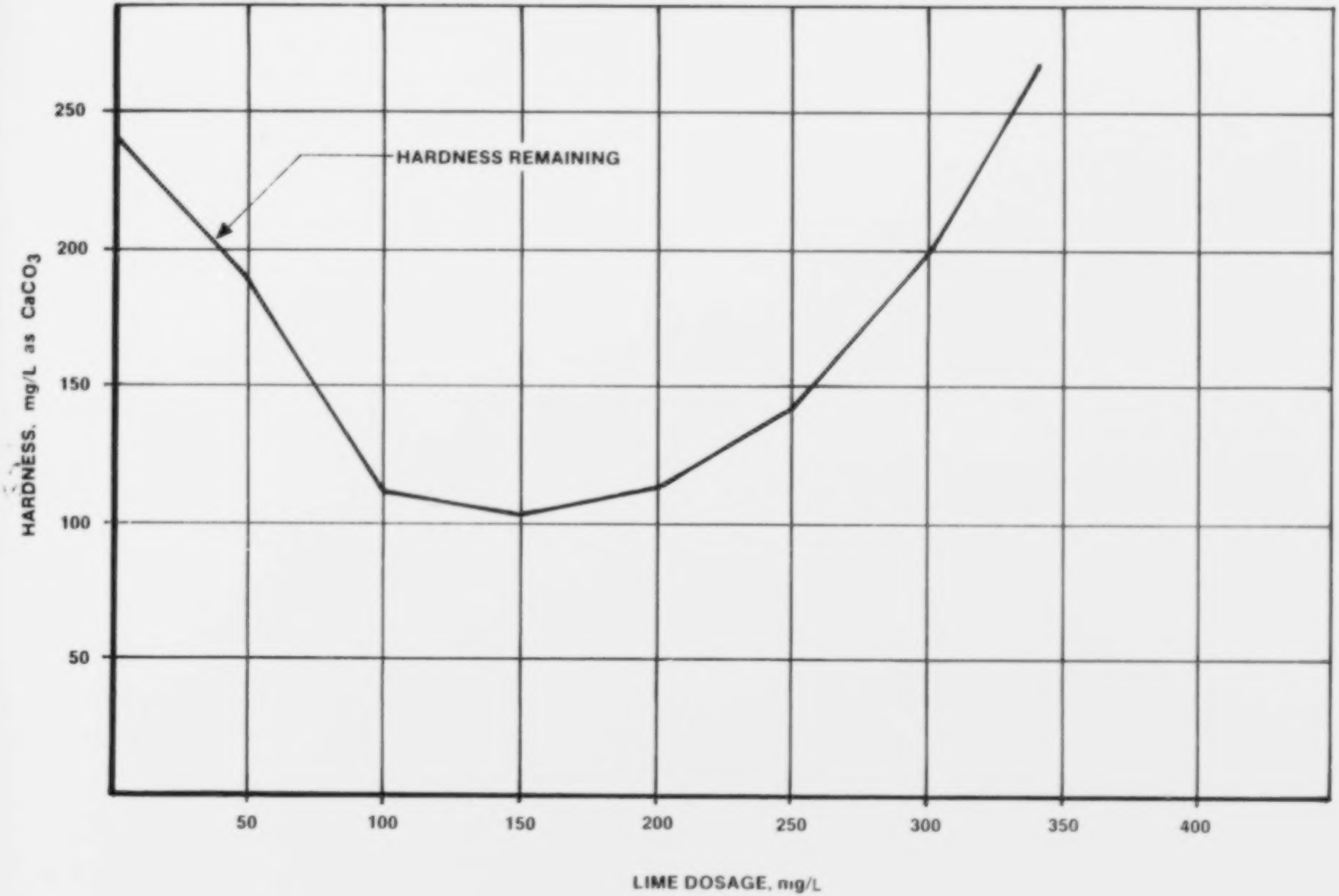

Fig. 4.20 Softening curve for City 1

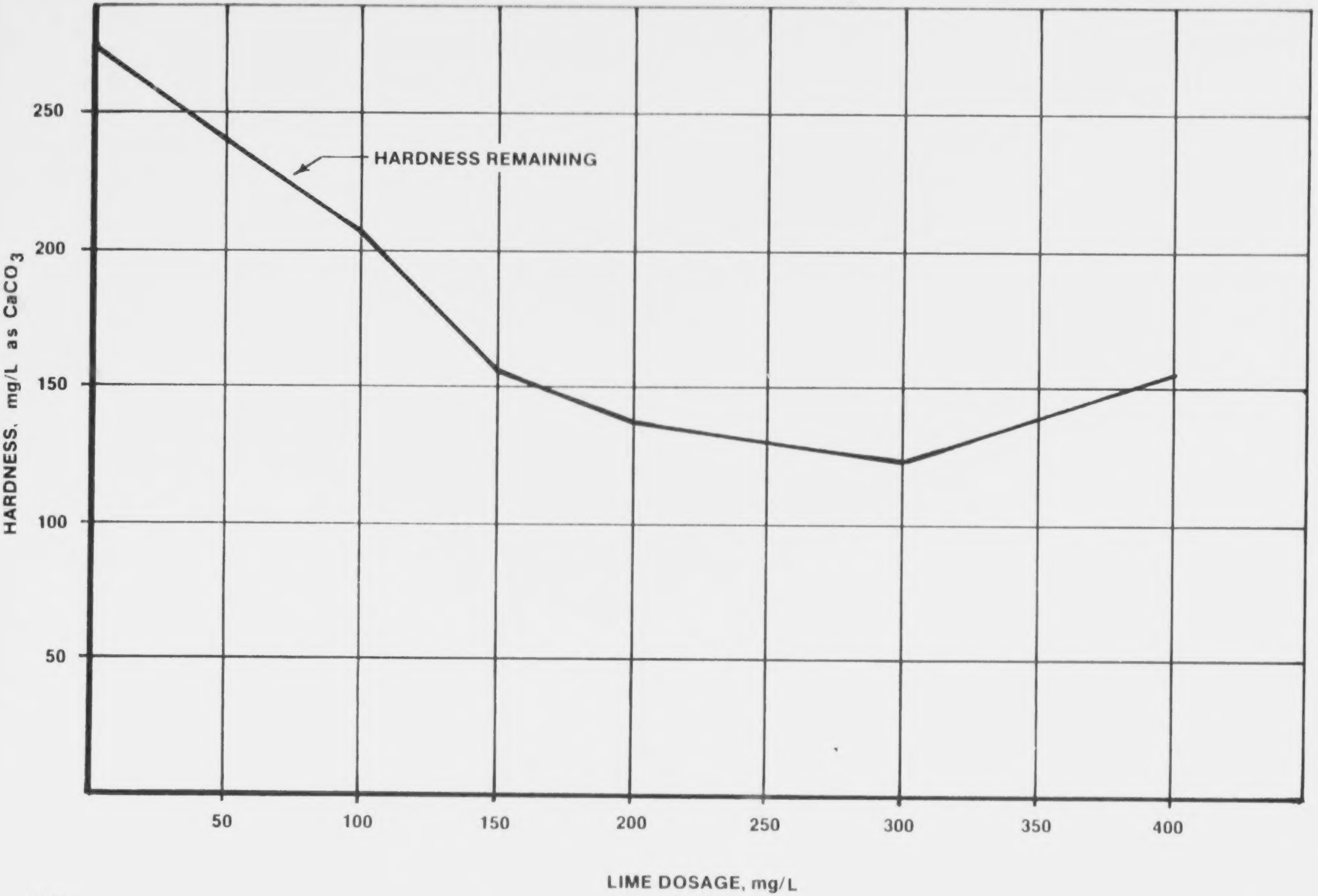

Fig. 4.21 Softening curve for City 2

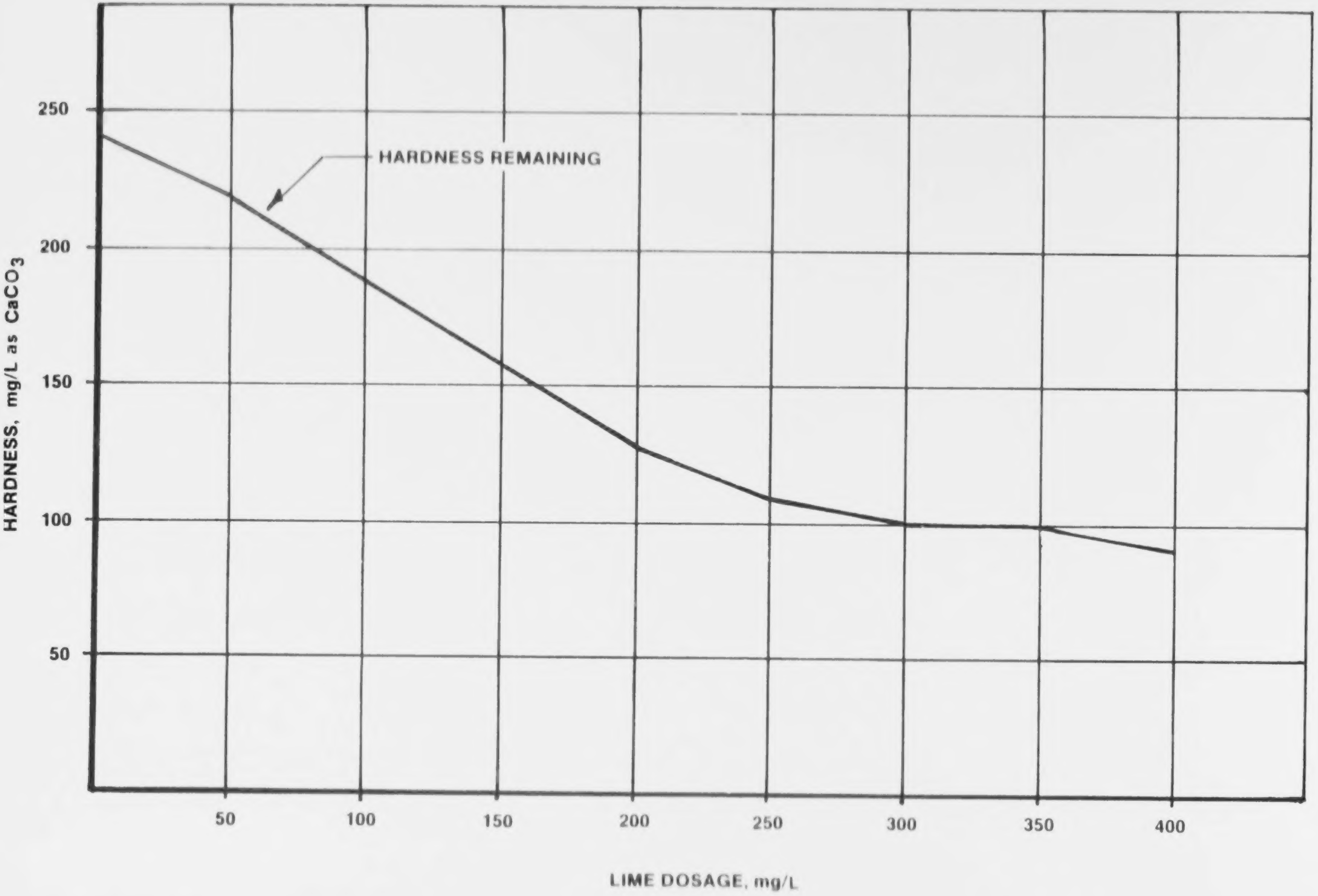

Fig. 4.22 Softening curve for City 3

problem in the unit. Try to find the source of the problem as soon as possible and correct the problem. The backwash duration and flow rate will vary depending on the manufacturer and the type of media used.

When the effluent from the zeolite softener no longer has zero hardness or your calculations (Example 14) indicate that the softener is reaching its exchange capacity, the softener must be regenerated. This process is called regeneration or the brine stage. In this stage, the sodium ions present in the brine solution are exchanged with the calcium and magnesium ions on the resin that have been removed during the service or softening stage. If the regeneration process is performed correctly, the result is a bed that is completely recharged with sodium ions and will again soften water when the unit is returned to service.

After the regeneration process is completed, the softener should be rinsed. The flow pattern is very similar to the service or softening stage, with the exception that the softener effluent is going to waste instead of storage. Most rinse stages will last from 20 to 40 minutes depending on the size of the unit and the manufacturer. The rinse must be long enough to remove all traces of the brine from the softener. Near the end of the rinse cycle, taste the effluent to be sure that no salty taste remains. If the effluent tastes OK, the unit is now ready to be returned to service. The effluent from the filter should have zero hardness if the regeneration process was successful.

Zeolite softeners will remove iron and manganese in the soluble or precipitated form. If water high in iron and manganese is applied to the ion exchange media for very long, iron fouling or the loss of exchange capacity could result. If the media becomes coated with iron, the media will develop a rusty or orange appearance and the efficiency of the softener will be greatly reduced. High iron loadings (in the ferric or solid form) can plug the upper layer of the media and force water to channel or short-circuit through the bed. This will result in incomplete or insufficient contact between the water and the media, thus creating hardness leakage and a loss in softening efficiency.

Disposal of spent brine can be a serious problem. The brine is corrosive to material it comes in contact with and is toxic to many living plants and animals in the environment. Each ion exchange treatment plant probably has only one approved method of spent brine disposal which must be carefully followed at all times.

The brine is corrosive to the brine carrying system; therefore, frequent inspection and routine maintenance is important. Immediately repair all leaks in the brine pumping and piping system and also in the brine storage area.

If the bed turns an orange or rusty color, iron fouling is becoming a problem. Try increasing the length of the backwash stage. A chemical cleaner (sodium bisulfite) can be used to remove heavy iron coatings from the media. The sodium bisulfite can be added to the brine during the regeneration stage or it may be mixed in solution form and poured into the softener when the softener is out of service. The softener should be rinsed before being returned to service.

The water produced by a zeolite softener has near zero hardness and is very corrosive. For these reasons, this water is mixed or blended with other water (untreated or unsoftened water) to produce water of acceptable hardness (80 to 90 mg/*L*) for the consumers. The amount of blend water depends on the desired level of hardness in the finished water.

In most cases ion exchange softening is used by smaller water softening plants instead of the lime-soda softening process due to economics. For additional information on water softening, see Chapter 14, "Softening," in *WATER TREATMENT PLANT OPERATION*, Volume II, in this series of manuals.

FORMULAS

The exchange capacity of ion exchange units is expressed in kilograins. Therefore, if an ion exchange unit has a capacity of 20 kilograins, the unit can remove 20 kilograins of hardness before requiring regeneration.

$$\text{1 grain per gallon or gpg} = 17.1\ \text{mg}/L$$

$$\text{Hardness, grains/gallon} = \frac{\text{Hardness, mg}/L}{17.1\ \text{mg}/L/\text{gpg}}$$

$$\text{Exchange Capacity, grains} = (\text{Media Vol, cu ft})(\text{Removal Capacity, grains/cu ft})$$

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gallon}}$$

$$\text{Operating Time, hr (Before Regeneration)} = \frac{(\text{Water Treated, gal})(24\ \text{hr/day})}{\text{Ave. Daily Flow, gal/day}}$$

EXAMPLE 14

A zeolite softener contains 200 cubic feet of media with a hardness removal capacity of 20 kilograins per cubic foot of media. The water being treated has a hardness of 250 mg/*L* as $CaCO_3$. How much water can be treated before the softener will require regeneration?

Known		Unknown
Media Volume, cu ft	= 200 cu ft	Water Treated, gal
Removal Capacity, gr/cu ft	= 20,000 grains/cu ft	
Hardness, mg/*L*	= 250 mg/*L*	

1. Convert the hardness from mg/*L* to grains per gallon.

$$\begin{aligned}\text{Hardness, grains/gal} &= \frac{\text{Hardness, mg}/L}{17.1\ \text{mg}/L/\text{gpg}}\\ &= \frac{250\ \text{mg}/L}{17.1\ \text{mg}/L/\text{gpg}}\\ &= 14.6\ \text{grains per gallon}\end{aligned}$$

2. Calculate the exchange capacity of the softener in grains.

$$\begin{aligned}\text{Exchange Capacity, grains} &= (\text{Media Vol, cu ft})(\text{Removal Capacity, grains/cu ft})\\ &= (200\ \text{cu ft})(20{,}000\ \text{grains/cu ft})\\ &= 4{,}000{,}000\ \text{grains}\end{aligned}$$

3. Calculate the volume of water in gallons that may be treated before regeneration.

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gallon}}$$

$$= \frac{4{,}000{,}000 \text{ grains}}{14.6 \text{ grains/gallon}}$$

$$= 274{,}000 \text{ gallons}$$

EXAMPLE 15

The zeolite softener described in Example 14 treats an average daily flow of 200,000 gallons of water per day. How often (hours) should the softener be regenerated? From Example 14, the softener can treat 274,000 gallons of water before requiring regeneration.

Known		Unknown
Water Treated, gal	= 274,000 gal	Operating Time, hr
Ave. Flow, gal/day	= 200,000 gal/day	

Calculate the number of hours the softener can operate before requiring regeneration.

$$\text{Operating Time, hr} = \frac{(\text{Water Treated, gal})(24 \text{ hr/day})}{\text{Ave. Daily Flow, gal/day}}$$

$$= \frac{(274{,}000 \text{ gal})(24 \text{ hr/day})}{200{,}000 \text{ gal/day}}$$

$$= 32.9 \text{ hours}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 219.

4.9D How does an ion exchange water softening process work?

4.9E When should a zeolite softener be backwashed?

4.9F How can you tell when the rinse cycle of a zeolite softener is adequate?

4.9G What problems does excessive iron cause in a zeolite softener?

4.10 OPERATION

The operators of water treatment plants must be responsible, knowledgeable, and conscientious. A poor operator may not do a good job with even the best equipment. Whereas a competent operator, who is conscientious and responsible, can often achieve good results with only ordinary or even inadequate equipment. Over and over again, experience has shown that it is the abilities of the operator that determine whether a water treatment plant produces acceptable quality water. Frequently large sums are spent on the design and construction of a water plant but all too often selection and training of the operator is hardly given a second thought. The need for a capable operator must not be ignored if the goal is to produce good water.

First of all, the operator must be interested in doing a good job. An operator must have the desire to produce the best quality water possible. Next, the operator should receive the necessary training. Prior experience in water treatment is very helpful but additional training is necessary. Many aspects of water treatment and water plant operation involve very technical or specialized subjects. These subjects include mathematics, hydraulics, water chemistry, water quality standards, electricity, plumbing, pumps, motors, bacteriology, recordkeeping and public relations. Classroom instruction is sometimes available but frequently the operator's only choice is individual study at home. However, when seminars, classes and meetings are offered, the operator should certainly attend. The operator of small systems can often receive very helpful training and assistance from the operators of large water treatment plants in the area. Try to visit other plants and become acquainted with the operators. They are usually glad to help another operator.

TONITE
WAT
CHEM

Operator certification programs are available now in most states. Certification may be granted under a program conducted by the local water works association or by the state government. In either case, the operator should enroll in the program for the training and educational benefits and try to become certified. Operator certification is important because it is evidence of the operator's level of knowledge and proficiency on the job. As a result, operator job descriptions for many water utilities now require certification before hiring. Water treatment plant operators are finding it harder than ever to find work as an operator without being certified.

CERTIFICATE

Following is a list of typical procedures the operator should follow in operating the small treatment plant.

DAILY

1. Inspect the plant daily including weekends and holidays. A trained substitute operator must be available when the regular operator is sick or on vacation.
2. Determine that all the plant equipment is operational.
3. Perform water quality and operational tests like chlorine residual, turbidity, pH and jar tests.

4. Actually smell and taste the treated water produced to detect any esthetic problems.
5. Record readings from flow meters, pressure gages, filter head loss gages and reservoir level gages.

PERIODICALLY

1. Dismantle, clean and overhaul chemical feeders like chlorinators and coagulant chemical feed pumps.
2. Test start standby pumps, motors and generators.
3. Perform "preventive maintenance" to inspect, lubricate, clean and repair equipment.
4. Replenish chemical stocks.
5. Clean settling basins and dispose of sludge.
6. Overhaul major equipment like filters, clarifiers and pumps.
7. Calibrate flow meters and chemical feeders.
8. Repaint piping, equipment and buildings.
9. Perform electrical efficiency tests on all pumps.
10. Test emergency alarms and control systems.
11. Maintain stock of repair parts and spare equipment.
12. Collect routine bacteriological samples and occasional chemical samples for laboratory analysis.

The operator needs to become acquainted with local contractors, regulatory agencies, and suppliers of chemicals, equipment and materials. Contractors must be hired occasionally to repair the water system, construct improvements and perform other services. The operator should be familiar with the capabilities of each contractor and the cost of necessary services. Regulatory agencies, such as the health department, can assist the operator in solving problems that arise. Likewise, suppliers of equipment and materials are often experts in their field and frequently give generously of their time to assist an operator in using their products successfully. These resources should not be overlooked. A lot of good advice is available without charge and the operator should not hesitate to ask for assistance from any of these sources when the need arises.

Records of water system operation are vital and must be kept up to date by the operator. The essential records include the following items.

1. *PLANT OPERATING DATA*

   This data includes the date-time that the plant was inspected, the operating flow rate, the amount of water treated, the dosage of chemicals being applied, the amount of chemicals fed, filter head loss, filter backwash time, reservoir levels and weather conditions.

2. *DAILY LOG OR DIARY*

   Many operators keep a daily diary to supplement and explain information recorded in the log of operating data. The operator's diary usually consists of informal notes and the operator is free to record any important comments, observations, reminders or explanations. The types of information recorded may include notes about equipment breakdowns; changes in treatment; severe weather; changes in water quality conditions or visits by repairmen, health inspectors, customers and other officials. This information is very helpful to the relief operator who must take over operation of the plant suddenly or on occasion.

3. *LABORATORY TEST RESULTS*

   Test results include those for tests performed by the operator as well as by private laboratories. The operator performs jar tests, measures turbidity, pH, chlorine residual and performs other simple chemical tests such as alkalinity. Complete chemical analyses and routine bacteriological sample testing is usually done by a private analytical laboratory. These test results must usually be reported to the health department and preserved for reference.

4. *SYSTEM RECORDS*

   System records include all available maps and drawings of the distribution system layout. These records are invaluable for locating pipelines, valves and service connections. The location, size, age and material of all pipelines should be shown on the plans.

   The operator should carefully preserve the plans and specifications for all structures including the treatment equipment and the storage reservoirs. These documents show the construction details on each piece of equipment or structure and they describe the materials that were used. The operator's files should also contain the technical manual and the maintenance records for each piece of equipment in the system. With this information available for reference, the operator should be able to understand how the system was built and how to keep it operating efficiently.

The backflow of polluted waters or liquids into the domestic water system must be prevented by a program of backflow prevention. Backflow, which is a reversal in the normal direction of flow, can occur in two ways. One way is backflow due to siphonage caused by vacuum conditions in the system. This backsiphonage is caused by a sudden major water demand such as a fire or a major system break. The second way is backflow due to pressure conditions created by a pump or other source of higher pressure.

Backflow from wastewater (sewage) facilities and from industrial or commercial operations is the most hazardous. Many hazardous chemicals and liquids are used in industry and these must be excluded from the water supply to prevent poisoning of consumers. Wastewater contains a variety of germs, often in great numbers, that can cause illness or death.

To limit backflow, the distribution system must be properly constructed and operated. Pipelines must be large enough to handle peak flows without creating vacuum conditions. Also, adequate pressures must be maintained in the system at all times. Pipeline outages and shutdowns should be limited and pipes thoroughly flushed before they are returned to service.

Water service connections to premises where backflow hazards exist should be protected with an appropriate backflow preventer. Typical types of backflow preventers include air gap separations, reduced pressure principle devices, double check valve assemblies and vacuum breakers. See Chapters 6 and 8 for details on backflow preventers.

For additional information on taste and odor control and plant operation, see Chapter 9, "Taste and Odor Control," and Chapter 10, "Plant Operation," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals. For information on fluoridation, see Chapter 13, "Fluoridation," in Volume II.

4.11 MAINTENANCE

4.110 Program

The water plant operator cannot afford to ignore the need for equipment maintenance. The water treatment plant must normally operate every day and equipment outages cannot be tolerated if the treatment is to be effective. Therefore the operator should strive to eliminate equipment breakdowns or at least minimize the time they cause the plant to be out of operation. Frequently, maintenance problems can be avoided by proper design or selection of the right piece of equipment.

Most other problems can be avoided if the operator will regularly inspect, clean and lubricate the equipment. Maintenance inspections should be performed according to a regular schedule which should be written down so inspections are not overlooked. Unusual noises, vibrations, leaks and malfunctions should receive prompt attention. Regular cleaning of chemical feeders for chlorine, alum and lime will prevent many breakdowns in this equipment. Spare parts should be kept on hand so breakdowns can be repaired quickly and so worn parts can be replaced when the feeder is disassembled for cleaning. Other chapters in this manual should be consulted for more specific details on equipment maintenance.

The operator is also responsible for maintaining clean and tidy conditions in the plant grounds. Plant piping, buildings and tanks should be painted regularly to prevent deterioration and to present a good public appearance. Pipes, plumbing fittings, chemicals, tools and other materials must be stored in a safe and orderly manner. Junk and clutter should be eliminated.

For additional information on maintenance, see Chapter 18, "Maintenance," and Chapter 19, "Instrumentation," in *WATER TREATMENT PLANT OPERATION*, Volume II, in this series of manuals.

4.111 Tools

Nothing makes a maintenance or repair job tougher than to have the wrong tools or no tools at all. The following list of tools is provided as a guide to help you determine the tools you will need to do your job. This list is not complete. You may need additional tools to do your job and some of the tools you will not need.

Proper care of tools is essential. You must maintain your tools and hand equipment as necessary and keep everything in proper working order. After a job is completed, clean your tools and store them properly so you can find them and use them when you need them.

LIST OF OPERATOR'S TOOLS

1. *WRENCHES*
   a. Deep-well socket set, ⅜" to 1¼" with ½" drive ratchet and "breaker bar"
   b. Pipe wrenchs, assorted sizes 6" to 36"
   c. Crescent wrenchs, assorted sizes 6" to 18"
   d. Combination open and box end wrench set ¼" to ¾"

   e. Allen wrench set
   f. Fire hydrant spanner wrench
   g. Gate valve wrench, 2" nut and 4" nut
   h. Corporation stop wrench

2. *SCREWDRIVERS* — Set, assorted sizes
3. *HAMMERS*
   a. Claw — 16 oz
   b. Ball peen — 16 oz and 8 oz
   c. Brass, rawhide, or soft plastic head
4. *SLEDGE HAMMERS*
   a. 2 pound
   b. 8 pound
5. *PLIERS*
   a. Slip joint common pliers
   b. Groove joint "channel lock" pliers
   c. Electric lineman's pliers
   d. Diagonal cutter pliers
   e. Needle nose pliers
   f. Vise grip pliers
   g. Electric terminal end pliers with wire stripper
   h. Fuse puller pliers
   i. Internal snap-ring pliers
   j. External snap-ring pliers
6. *HACKSAW*
7. *METAL FILES* — set of round and flat
8. *LIGHTS*
   a. 2 cell flashlight
   b. 6 volt battery lantern
9. *MEASURING TAPE*
   a. 10′ retractable steel
   b. 100′ cloth
10. *SHOVEL*
    a. Round point, heavy duty
    b. Square end
11. *PICK*
12. *PIPE VISE* — Truck mounted
13. *FLARING TOOLS AND CUTTER* — For copper and plastic pipe
14. *TUBING BENDER*
15. *CRIMPING TOOL* — For emergency shut off of service pipes
16. *POCKET KNIFE* — Folding with blade lock feature
17. *GASKET SCRAPER TOOL*
18. *COLD CHISELS AND PUNCHES* — Set, assorted sizes
19. *PUTTY KNIFE*
20. *MANHOLE COVER PULLER HOOK*
21. *ELECTRIC DRILL* — ½" reversible
22. *DRILL BITS* — Set, assorted sizes
23. *TAP AND DIE SET*
24. *"EASY OUTS"* — Set
25. *STUD BOLT PULLER*
26. *PACKING REMOVAL HOOKS* — Flexible, set of sizes
27. *LANTERN RING REMOVAL TOOLS* — Set
28. *PIPE CUTTING TOOLS* — Manual or electric power
29. *WIRE BRUSHES*
30. *STEEL PRY BARS* — 8′ long
31. *EXTENSION LADDER* — Aluminum
32. *"COME-A-LONG"* — 2 ton capacity
33. *CHAIN HOIST* — 2 ton capacity
34. *NYLON ROPE* — ½" diameter
35. *WATER PRESSURE GAGE* — With connection to hose faucet
36. *FIRE HOSE* — 50 ft.
37. *MUD PUMP* — 3" positive displacement, gasoline powered
38. *CLOTHING*
    a. Rain suit — pants and jacket with hood or hat
    b. Rubber boots — calf length, hip length
    c. Rubber gloves
    d. Hard hat
    e. Face mask, clear plastic
    f. Eye goggles
    g. Leather gloves
39. *ELECTRIC VOLTAGE TESTER* — 110 to 600 volts
40. *VOLTMETER/AMMETER TESTER* — "Amprobe"
41. *WATER TEST KITS*
    a. Chlorine residual
    b. pH
    c. Turbidimeter
42. *AMMONIA SOLUTION* — Industrial strength
43. *CHLORINE BLEACH* — Sodium hypochlorite
44. *CHLORINE TABLETS* — Calcium hypochlorite
45. *BREATHING MASK* — Self contained, MSA
46. *RESPIRATOR MASK* — With replaceable filters
47. *GREASE GUN* — With graphite cartridges
48. *ELECTRONIC CALCULATOR*
49. *OPERATION MANUALS* — For plant equipment
50. *TOOL BOXES* — Lockable steel
51. *WIPING RAGS*
52. *PLASTIC ELECTRICAL TAPE*
53. *FIRST AID KIT*
54. *PUSH BROOM* — Heavy duty
55. *PERMATEX NO. 1* — Gasket adhesive

4.12 SAFETY

When operating any type of water treatment facility,

Safety must always come first!

If you are the only operator at a small water treatment plant, you must take care of yourself. There frequently is no one else present to make sure that you follow safe procedures and that there are no safety hazards that can injure you. There may be no one else available to help you or to rescue you if you become injured.

Safety hazards of concern around any water treatment plant include chlorine, electrical shock, and drowning. Studies have shown that the greatest causes of injuries to operators result from muscle and back strains caused by lifting and injuries resulting from slips and falls. These types of injuries can easily be prevented by alert and safety-conscious operators.

In Section A.13, "Typical Small Water System Operation Problems," read and work the problems in the following sections:

Be extremely careful whenever working with chlorine. If you are wearing a self-contained (or airline) breathing apparatus and the respirator fails, you could be overcome by a toxic gass or a lack of oxygen. Under these circumstances, two people should always be standing by for rescue purpose. The following rules are recommended:

1. Two (2) people *SHOULD* be present whenever entrance to a gas chlorine feed station and/or gas chlorine storage area (building or yard) is attempted.
2. Two (2) people *SHALL* be present when any type of maintenance, repair work, and/or work which might create a chlorine leak is attempted.
3. Two (2) approved, self-contained (or airline) supplied air masks *SHALL* be available prior to entering a gas chlorine feed station and/or gas chlorine storage area.

NOTE: "SHOULD" indicates that a safety regulation will normally be followed as closely as possible, consistent with good judgement. *"SHALL"* indicates that compliance with a safety regulation is mandatory at all times.

For additional information on safety, see Chapter 6, "Safety," in this manual and also Chapter 20, "Safety," in *WATER TREATMENT PLANT OPERATION*, Volume II, in this series of manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 219.

4.10A Why should operators become certified?

4.10B List the essential records that must be kept up to date by the operator.

4.10C Which laboratory tests are commonly performed by operators?

4.11A How can the operator avoid maintenance problems?

4.12A What are the greatest causes of injuries to operators?

4.13 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read all of Section A.4, "Metric System."

In Section A. 13, "Typical Small Water System Operation Problems," read and work the problems in the following sections:

1. A.130 — Flows,
2. A.131 — Chemical Doses,
3. A.132 — Wells, and
4. A.133 — Small Water Treatment Plants.

4.14 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 1, "Purpose of Water Treatment," and Chapter 19, "Treatment Plant Maintenance and Accident Prevention."
2. *TEXAS MANUAL*, Chapter 25, "Water Treatment Plant Waste Disposal."

End of Lesson 2 of 2 Lessons on SMALL WATER TREATMENT PLANTS

DISCUSSION AND REVIEW QUESTIONS

Chapter 4. SMALL WATER TREATMENT PLANTS

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the objective test on page 220. The problem numbering continues from Lesson 1.

13. How can corrosion be controlled?
14. Why should corrosion control chemicals be applied to water after all other treatment has been accomplished?
15. Sudden changes in what three factors can cause operating problems in solids-contact units?
16. What problems can develop in a solids-contact unit if the recirculation rate is too high or too low?
17. Why must the dose of potassium permanganate for the control of iron and manganese be exact?
18. Why do the results of jar tests often not produce the same results in a water treatment plant using the lime-soda ash softening process?
19. How often should the chemical dosages be checked in a lime-soda ash water softening plant?
20. What is the optimum flow rate through an ion exchange softener?
21. Plant operating data includes what types of information?
22. How can the backflow of polluted waters or liquids into the domestic water system occur?
23. Why is safety especially important for the operator of a small water treatment plant?

SUGGESTED ANSWERS

Chapter 4. SMALL WATER TREATMENT PLANTS

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 167.

4.0A Water supplies that need no treatment are very rare because of pollution and more restrictive standards for domestic water quality.

4.0B Storage of raw water in lakes, ponds or reservoirs helps the operator by slowing the rate of change in water quality due to storms and other factors.

4.0C A flow meter indicates to the operator both the instantaneous rate of flow as well as the total quantity of water that has flowed through it.

4.0D Flow meters can be protected by a fine screen or wye strainer installed upstream from the meter to prevent clogging or damage by trash or rocks.

4.0E Treatment that may be required by groundwaters includes disinfection, iron and manganese control, and softening.

Answers to questions on page 174.

4.1A The warmer the water, the faster the coagulation chemical reactions. Any chemical reaction proceeds faster when the water is warm than when it is cold.

4.1B The results of jar tests can be evaluated by visual observations or by performing further laboratory tests. Visual observations include which coagulant dosage produces the first visible floc, which produces the largest, strongest floc, or which produces the floc that settles the fastest. Laboratory tests include (1) the pH of the water, (2) the turbidity of the settled water, and (3) the filterability of the water as determined by filtration through some type of small laboratory filter.

4.1C To determine whether the coagulant dose should be increased or decreased, collect a sample from the outlet of the rapid mix chamber and use this water for the jar test. Add additional doses of coagulant to two jars and dilute a couple of jars with raw water. Observing the results can indicate whether the dosage should be increased or decreased.

4.1D The alkalinity of the water being treated can be increased by adding lime or soda ash prior to coagulation.

Answers to questions on page 175.

4.2A Flocculation is a process of slow, gentle mixing of the water to encourage the tiny floc particles to clump together and grow to a size that will settle quickly.

4.2B Flocculation mixing must be strong enough to prevent premature settling of floc in the flocculation basin, but the mixing must not be so strong that it breaks apart the floc particles already formed.

Answers to questions on page 180.

4.3A The purpose of settling is to remove as much of the floc and other suspended material as possible before the water flows to the filters.

4.3B Short-circuiting depends on (1) the shape and dimensions of the tank, and (2) the inlet and outlet arrangements of the tank.

4.3C The warmer the water, the faster the particles settle.

4.3D Sludge is recycled to the inlet of the settling tank to increase the number of particles in the water and improve flocculation of the settling particles.

Answers to questions on page 187.

4.4A Suspended matter removed by filtration includes mainly particles of floc, soil, and trash; but it also includes living organisms like algae, bacteria, virus and protozoa.

4.4B Anthracite and sand stay separated during and after backwashing because sand is about two and a half times heavier than water and anthracite is only one and a half times heavier than water.

4.4C A mixed media filter contains three layers of media, (1) garnet, (2) sand, and (3) anthracite.

4.4D Mudballs will form in filters if backwashing does not effectively clean the media.

Answers to questions on page 198.

4.5A Domestic water supplies are usually disinfected with chlorine, although iodine, ozone and ultraviolet radiation are also used occasionally.

4.5B Chlorine is available as (1) gaseous chlorine, (2) liquid chlorine as bleach (sodium hypochlorite), (3) granular or tablet (calcium hypochlorite), and (4) chlorine dioxide.

4.5C A chlorinator controls and measures the flow of chlorine gas and also dissolves the gas in water so it can be safely injected into the water supply.

4.5D Substances found in water which react with and consume chlorine include ammonia, dissolved iron and manganese, hydrogen sulfide and organic matter.

4.5E The two types of chlorine residuals that can be measured with test kits include (1) free available chlorine, and (2) total chlorine residual.

4.5F Calculate the desired chlorine residual for a water with a pH of 7.6 when the water is 5°C. The contact time is 25 minutes.

Known		Unknown
Time, min	= 25 min	Chlorine Residual, mg/*L*
pH	= 7.6	
Temp, °C	= 5°C	
A from Table 4.1	= 20	

Calculate the desired free chlorine residual in mg/L.

$$\text{Chlorine Residual, mg/}L = \frac{\text{A from Table 4.1}}{\text{Contact Time, min}}$$

$$= \frac{20}{25 \text{ min}}$$

$$= 0.8 \text{ mg/}L \text{ free chlorine residual}$$

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 200.

4.6A The two general methods of controlling corrosion are (1) use of construction materials that resist corrosion and (2) treatment of the water with chemicals to make the water noncorrosive.

4.6B The best method of monitoring corrosion in a water main is to examine specimens of the actual pipeline material. This inspection is easy if sections of pipe can be removed periodically. Alternatively, small specimens of the pipeline material can be mounted in the flowing water and periodically removed for inspection.

Answers to questions on page 204.

4.7A Two advantages of solids-contact units include:

1. Only one reaction unit to contend with,
2. Ability to accumulate slurry during periods of severe taste and odor problems, and
3. Use slurry accumulation to carry plant when coagulation fails because of increased algal activities.

4.7B The level of the slurry or sludge blanket can be determined by sampling taps which are placed at various depths on the wall of the solids-contact reactor.

4.7C Operators should attempt to forecast turbidity changes and adjust chemical dosage prior to the arrival of a turbidity change.

Answers to questions on page 206.

4.7D The jar test is used to determine the proper chemical dose when operating a solids-contact unit. Observations and process monitoring are used to "fine tune" the results from jar tests.

4.7E Recirculation in a solids contact unit may be provided by impellers, turbines, pumping units or by air injection.

4.7F The percent slurry in the reaction zone is determined by the volume over volume (V/V) test.

Answers to questions on page 207.

4.8A Excessive amounts of iron and manganese in drinking waters are objectionable because they stain clothes and encourage the growth of iron bacteria. These bacteria form thick slimes on the walls of pipes which break away and cause rust-colored water, black particles and foul tastes and odors.

4.8B Greensand is sometimes used to treat iron and manganese because it is capable of both oxidation and filtration.

4.8C The main advantage of treating iron by aerating water is that no chemicals are required.

4.8D When using ion exchange units to remove iron and manganese there must be no dissolved oxygen present. Dissolved oxygen causes the resins to become fouled with iron rust or manganese dioxide.

Answers to questions on page 208.

4.9A The procedures for softening water by chemical precipitation using the lime-soda ash process depend on the hardness and other chemical characteristics of the water being treated (pH, alkalinity, temperature).

4.9B If lime added to water does not remove sufficient hardness, select the optimum lime dose and then add enough soda ash to lower the hardness to the 80 to 90 mg/L hardness as $CaCO_3$ range.

4.9C Softened waters from the lime-soda ash process must be recarbonated to lower the pH and stabilize the water to prevent the precipitation of carbonate compounds on the filter media, in the clear well and in the pipes in the distribution system.

Answers to questions on page 213.

4.9D In an ion exchange water softening process, the hardness-causing ions (mainly calcium and magnesium) are exchanged or traded for sodium ions by passing the water through an ion exchange media.

4.9E A zeolite softener should be backwashed if design flows cannot be put through the softener or the head loss through the softener becomes greater than normal.

4.9F The rinse cycle of a zeolite softener is adequate when the effluent from the rinse cycle no longer has a salty taste.

4.9G Iron loadings can cause a zeolite softener to lose its exchange capacity, to plug and to force water to channel or short-circuit through the bed.

Answers to questions on page 217.

4.10A Operators should become certified because it is evidence of the operator's level of knowledge and proficiency on the job.

4.10B Records that must be kept up to date by the operator include

1. Plant operating data,
2. Daily log or diary,
3. Laboratory test results, and
4. System records.

4.10C Laboratory tests which are commonly performed by operators include jar tests, turbidity, pH, chlorine residual and alkalinity.

4.11A Maintenance problems can be avoided by regular inspection, cleaning and lubrication of equipment. Unusual noises, vibrations, leaks and malfunctions should receive prompt attention.

4.12A The greatest causes of injuries to operators result from muscle and back strains caused by lifting and injuries resulting from slips and falls.

OBJECTIVE TEST

Chapter 4. SMALL WATER TREATMENT PLANTS

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True — False

1. Large water treatment plants are much more numerous than small plants.
   1. True
   2. False
2. The most common coagulating chemical is lime.
   1. True
   2. False
3. Hydraulic mixers are preferred over mechanical mixers for flocculation.
   1. True
   2. False
4. The pH of the water being treated must be controlled within a narrow range during coagulation to achieve optimum results.
   1. True
   2. False
5. A relatively clear water is easier to flocculate than a turbid water containing a lot of suspended matter.
   1. True
   2. False
6. Unless adequate chemical coagulation and flocculation treatment is provided prior to filtration, fine particles of suspended matter will easily flow between the grains of filter media and pass through the filter without being removed.
   1. True
   2. False
7. The higher the settling tank overflow rate, the greater the particle removal.
   1. True
   2. False
8. Ammonia combines readily with chlorine to form chloramine compounds.
   1. True
   2. False
9. A glass of water may be sparkling clear and appear to be pure, but may contain harmful bacteria.
   1. True
   2. False
10. Only fully treated water should be used for filter backwashing.
    1. True
    2. False
11. A lower flow rate is necessary for backwashing filters when the water is warm, than when it is cold.
    1. True
    2. False
12. Raw sand from a river is a suitable filter media.
    1. True
    2. False
13. The interior arrangement of pressure filters is identical for all manufacturers.
    1. True
    2. False
14. If a plant treating surface waters has only one chlorinator and it fails, the plant must be shut down until the chlorinator is repaired.
    1. True
    2. False
15. Chloramines are a much stronger disinfectant than free chlorine.
    1. True
    2. False
16. Returning a portion of the previously settled sludge provides an excellent coagulation aid to the flocculation process.
    1. True
    2. False
17. Solids-contact units are used to remove turbidity from drinking water.
    1. True
    2. False
18. Waters with a lower pH are normally less corrosive than waters with a higher pH.
    1. True
    2. False
19. When treated water is stored in open reservoirs, phosphate compounds are the most desirable chemicals for corrosion control.
    1. True
    2. False
20. The caliber of the person that operates the water treatment plant is more important than any other factor involved in the production of good quality water.
    1. True
    2. False
21. The most common type of ion exchange softener is the pressure up-flow type.
    1. True
    2. False

22. A zeolite water softening plant should deliver water of zero hardness to consumers.

    1. True
    2. False

23. A disadvantage of the solids-contact unit is the accumulation of slurry (sludge blanket).

    1. True
    2. False

24. Records of water system operation are vital and must be kept up to date by the operator.

    1. True
    2. False

25. Backflow due to siphonage is caused by vacuum conditions in the water supply system.

    1. True
    2. False

Multiple Choice

26. Small water treatment plants serve groups of people in

    1. Big cities.
    2. Larger service areas.
    3. Resorts.
    4. Rural subdivisions.
    5. Summer camps.

27. Short-circuiting in flocculators can be corrected by

    1. Adjusting pH.
    2. Increasing coagulant dosages.
    3. Increasing flows.
    4. Proper baffling.
    5. Providing several compartments in series.

28. The time of mixing during flocculation is usually

    1. 1 to 2 minutes.
    2. 2 to 5 minutes.
    3. 5 to 10 minutes.
    4. 30 to 45 minutes.
    5. 1 to 2 hours.

29. What factors could cause the use of excessive dosages of coagulant?

    1. Backflow conditions
    2. Equipment malfunction
    3. Improper chemical feeder setting
    4. Improper jar testing
    5. Operator error

30. Important factors that affect the coagulation process include

    1. Coagulant dosage.
    2. Coagulant used.
    3. Injection-mixing arrangement.
    4. pH of water.
    5. Water temperature.

31. Common settling times in water treatment plants range from

    1. 1 to 15 minutes.
    2. 15 to 30 minutes.
    3. 30 to 45 minutes.
    4. 1 to 2 hours.
    5. 2 to 4 hours.

32. The zones in a settling tank include

    1. Flocculation.
    2. Inlet.
    3. Outlet.
    4. Settling.
    5. Sludge.

33. Filter media may consist of

    1. Anthracite.
    2. Diatomaceous earth.
    3. Loam.
    4. Sand.
    5. Soil.

34. Currents in settling tanks may be caused by

    1. Design.
    2. Flow inertia.
    3. Sludge scrapers.
    4. Temperature differences.
    5. Wind action.

35. What factors influence the backwash flow rate for a dual-media filter?

    1. Size of media
    2. Specific gravity of media
    3. Suspended particles in water being filtered
    4. Temperature of water
    5. Underdrain system material

36. The purposes of the underdrain system of a filter include

    1. Collect filtered water.
    2. Drain seepage waters.
    3. Filter suspended particles.
    4. Support filtering media.
    5. Uniform distribution of backwash water.

37. A properly operated filter plant should easily produce treated water with a turbidity of no more than

    1. 1.0 Turbidity Units.
    2. 2.0 Turbidity Units.
    3. 4.0 Turbidity Units.
    4. 6.0 Turbidity Unit.
    5. 10.0 Turbidity Units.

38. Filters require backwashing when

    1. Backwash tank is full.
    2. Filters become plugged.
    3. Turbidity increases in raw water.
    4. Turbidity of filtered water increases.
    5. Water temperature changes.

39. Types of disease-causing organisms include

    1. Bacteria.
    2. Coliforms.
    3. Garnet.
    4. Protozoa.
    5. Virus.

40. Chlorine may be purchased for disinfection as

    1. Calcium hypochlorite.
    2. Hypochlorous acid.
    3. Liquid chlorine.
    4. Muriatic acid (HCl).
    5. Sodium hypochlorite.

41. If you are having problems achieving adequate disinfection, possible causes include
    1. Chlorinator overfeeding.
    2. Chlorine being consumed by organic matter.
    3. Chlorine being destroyed by exposure to sunlight.
    4. Contact time too long.
    5. Insufficient turbidity in water.

42. Effectiveness of disinfection of water with chlorine depends on
    1. Degree of mixing.
    2. pH of water.
    3. Presence of interfering substances.
    4. Time of chlorine contact.
    5. Turbidity of water.

43. Problems caused by corrosion include
    1. Decrease in flow capacity of pipelines.
    2. Discolored water.
    3. Harmful concentrations of copper, zinc and lead.
    4. Increase in pumping costs.
    5. Unpleasant tastes.

44. Water is frequently corrosive to materials it contacts, especially
    1. Cement linings.
    2. Coal tar enamel.
    3. Galvanized pipe.
    4. Iron.
    5. Plastic.

45. Which one of the following water quality indicators is frequently used as a day-to-day indicator of the corrosive nature of water?
    1. Acidity
    2. Alum
    3. Hardness
    4. pH
    5. Turbidity

46. Chemicals used to make water noncorrosive include
    1. Caustic soda.
    2. Lime.
    3. Muriatic acid.
    4. Polyphosphates.
    5. Soda ash.

47. Solids-contact units are effective for controlling
    1. Algal activities.
    2. Corrosivity.
    3. Hardness.
    4. pH.
    5. Tastes and odors.

48. Factors which can cause the level of the slurry pool to rise in a solids contact unit include
    1. Sludge discharge too great.
    2. Slurry concentration too low in proportion to the source water rate of flow.
    3. Sudden change in chemical characteristics of source water.
    4. Sudden change in source water turbidity.
    5. Sudden drop in source water temperature.

49. Excessive effluent turbidity from solids contact units may be caused by
    1. Excessive concentrator sludge discharge causing too high a slurry pool.
    2. Improper chemical treatment.
    3. Incomplete coagulation.
    4. Increase in source water turbidity.
    5. Too low a circulation rate.

50. A typical water softening plant should be able to deliver water of approximately ________ mg/*L* hardness to consumers.
    1. 0
    2. 50
    3. 100
    4. 150
    5. 200

51. Which of the following chemicals may be used to control iron and manganese?
    1. Alum
    2. Caustic soda
    3. Chlorine
    4. Polyphosphate
    5. Potassium permanganate

52. Tasks that should be done periodically by the operator of a small water treatment plant include
    1. Calibrate chemical feeders.
    2. Complete daily operating records.
    3. Perform electrical efficiency tests on pumps.
    4. Repaint piping.
    5. Test emergency alarms and control systems.

53. Every day the operator of a small water treatment plant should
    1. Clean settling basins and dispose of sludge.
    2. Determine that all plant equipment is operational.
    3. Replenish chemical stock.
    4. Smell and taste the treated water produced.
    5. Test start standby pumps, motors and generators.

54. Typical types of backflow preventers include
    1. Air gap separators.
    2. Double check valve assemblies.
    3. Gate valves.
    4. Reduced pressure principle devices.
    5. Vacuum breakers.

55. A zeolite softener contains 80 cubic feet of media with a hardness removal capacity of 20 kilograins per cubic foot of media. The water being treated has a hardness of 240 mg/*L* as $CaCO_3$. How much water can be treated before the softener will require regeneration? Select the closest answer.
    1. 114,000 gallons
    2. 119,000 gallons
    3. 129,000 gallons
    4. 143,000 gallons
    5. 171,000 gallons

56. Jar tests indicate that water should be dosed with alum at 12 mg/*L*. The flow being treated is 220 GPM. What is the desired alum feed in pounds per day?
    1. 28 lbs/day
    2. 32 lbs/day
    3. 36 lbs/day
    4. 40 lbs/day
    5. 45 lbs/day

57. The optimum dose of liquid alum from the jar tests is 15 mg/*L*. Determine the setting on the liquid alum chemical feeder in gallons per day when the flow is 0.5 MGD. The liquid alum delivered to the plant contains 5.36 pounds of alum per gallon of liquid solution.

$$\text{Chemical Feeder Setting, GPD} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(8.34\ \text{lbs/gal})}{\text{Liquid Alum, lbs/gal}}$$

1. 1.2 GPD
2. 2.4 GPD
3. 4.8 GPD
4. 6.7 GPD
5. 7.5 GPD

58. Calculate the actual chlorine dose in milligrams per liter. The hypochlorinator delivers 14 pounds of chlorine per day and the flow rate of the water being treated is 900,000 gallons per day (0.90 MGD).

1. 0.75 mg/*L*
2. 1.2 mg/*L*
3. 1.9 mg/*L*
4. 2.2 mg/*L*
5. 5.7 mg/*L*

59. A rectangular settling basin 28-feet long, 14-feet wide and 7-feet deep treats a flow of 180,000 gallons per day. Estimate the detention time in the basin for this flow.

1. 1.4 hr
2. 1.8 hr
3. 2.4 hr
4. 2.7 hr
5. 3.1 hr

60. A water treatment plant filter treats a flow of 400 GPM. The sand filter is 15-feet long by 15-feet wide. Determine the filtration rate in gallons per minute per square foot of filter.

1. 1.0 GPM/sq ft
2. 1.4 GPM/sq ft
3. 1.9 GPM/sq ft
4. 3.3 GPM/sq ft
5. 3.8 GPM/sq ft

End of Objective Test

CHAPTER 5

DISINFECTION

by

Tom Ikesaki

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Chapter 5. Disinfection

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OBJECTIVES

Chapter 5. DISINFECTION

Following completion of Chapter 5, you should be able to:

1. Disinfect new and existing wells,
2. Disinfect mains,
3. Calculate chlorine dosage,
4. Determine hypochlorinator and chlorinator settings,
5. Operate and maintain hypochlorinators,
6. Operate and maintain chlorinators,
7. Troubleshoot chlorination systems, and
8. Conduct a chlorine safety program.

GLOSSARY

Chapter 5. DISINFECTION

AMPEROMETRIC (am-PURR-o-MET-rick) AMPEROMETRIC

Based on the electric current that flows between two electrodes in a solution.

AMPEROMETRIC TITRATION (am-PURR-o-MET-rick) AMPEROMETRIC TITRATION

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction.

BACTERIA (back-TEER-e-uh) BACTERIA

Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BREAKPOINT CHLORINATION BREAKPOINT CHLORINATION

Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

CARCINOGEN (car-SIN-o-jen) CARCINOGEN

Any substance which tends to produce a cancer in an organism.

CHLORAMINES (KLOR-uh-means) CHLORAMINES

Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

CHLORINATION (KLOR-uh-NAY-shun) CHLORINATION

The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results (aiding coagulation and controlling tastes and odors).

CHLORINE DEMAND CHLORINE DEMAND

Chlorine demand is the difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

Chlorine Demand, mg/*L* = Chlorine Demand, mg/*L* − Chlorine Residual, mg/*L*

CHLORINE REQUIREMENT CHLORINE REQUIREMENT

The amount of chlorine which is needed for a particular purpose. Some reasons for adding chlorine are reducing the number of coliform bacteria (Most Probable Number), obtaining a particular chlorine residual, or oxidizing some substance in the water. In each case a definite dosage of chlorine will be necessary. This dosage is the chlorine requirement.

CHLORORGANIC (klor-or-GAN-ick) CHLORORGANIC

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.

CHLOROPHENOLIC (klor-o-FEE-NO-lick) CHLOROPHENOLIC

Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.

COLIFORM (COAL-i-form) COLIFORM

A group of bacteria which are found in the intestine of warm blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhabit the intestines of warm blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.

COMBINED AVAILABLE RESIDUAL CHLORINE COMBINED AVAILABLE RESIDUAL CHLORINE

The concentration of residual chlorine which is combined with ammonia (NH_3) and/or organic nitrogen in water as a chloramine (or other chloro derivatives) yet is still available to oxidize organic matter and utilize its bactericidal properties.

COMBINED RESIDUAL CHLORINATION COMBINED RESIDUAL CHLORINATION

The application of chlorine to water to produce a combined available residual chlorine. The residual can be made up of monochloramines, dichloramines, and nitrogen trichloride.

DISINFECTION (dis-in-FECK-shun) DISINFECTION

The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

DPD (pronounced as separate letters) DPD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N, N-diethyl-p-phenylene-diamine.

EDUCTOR (e-DUCK-ter) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump. As an injector, it is used to produce vacuum for chlorinators.

ENTERIC ENTERIC

Of intestinal origin, especially applied to wastes or bacteria.

ENZYMES (EN-zimes) ENZYMES

Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biological catalysts.

FREE AVAILABLE RESIDUAL CHLORINE FREE AVAILABLE RESIDUAL CHLORINE

That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl_2), hypochlorous acid ($HOCl$), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

HEPATITIS (HEP-uh-TIE-tis) HEPATITIS

Hepatitis is an inflammation of the liver usually caused by an acute viral infection. Yellow jaundice is one symptom of hepatitis.

HTH (pronounce as separate letters) HTH

High **T**est **H**ypochlorite. Calcium hypochlorite or $Ca(OCl)_2$.

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

A chemical reaction in which a compound is converted into another compound by taking up water.

HYPOCHLORINATION (hi-po-KLOR-uh-NAY-shun) HYPOCHLORINATION

The application of hypochlorite compounds to water for the purpose of disinfection.

HYPOCHLORITE (hi-po-KLOR-ite) HYPOCHLORITE

Chemical compounds containing available chlorine; used for disinfection. They are available as liquids (bleach) or solids (powder, granules and pellets). Salts of hypochlorous acid.

MPN (pronounce as separate letters) MPN

MPN is the **M**ost **P**robable **N**umber of coliform-group organisms per unit volume of sample water. Expressed as the number of organisms per 100 *mL* of sample water.

NITROGENOUS (ny-TRAH-jen-us) NITROGENOUS

A term used to describe chemical compounds (usually organic) containing nitrogen in combined forms. Proteins and nitrates are nitrogenous compounds.

ORTHOTOLIDINE (or-tho-TOL-uh-dine) ORTHOTOLIDINE

Orthotolidine is a colorimetric indicator of chlorine residual. If chlorine is present, a yellow-colored compound is produced. This reagent is no longer approved for chemical analysis.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDIZING AGENT OXIDIZING AGENT

Any substance, such as oxygen (O_2) and chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a REDUCING AGENT.

PALATABLE (PAL-a-ta-ble) PALATABLE

Water at a desirable temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

PATHOGENIC ORGANISMS (path-o-JEN-nick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of bacteria which do NOT cause disease. These organisms are called non-pathogenic.

PHENOLIC COMPOUNDS (FEE-noll-LICK) PHENOLIC COMPOUNDS

Organic compounds that are derivatives of benzene.

POSTCHLORINATION POSTCHLORINATION

The addition of chlorine to the plant effluent, *FOLLOWING* plant treatment, for disinfection purposes.

POTABLE WATER (POE-ta-bl) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

PRECHLORINATION PRECHLORINATION

The addition of chlorine at the headworks of the plant *PRIOR TO* other treatment processes mainly for disinfection and control of tastes, odors, and aquatic growths. Also applied to aid in coagulation and settling.

PRECURSOR, THM (pre-CURSE-or) PRECURSOR, THM

Natural organic compounds found in all surface and groundwaters. These compounds *MAY* react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs); they *MUST* be present in order for THMs to form.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

REDUCING AGENT REDUCING AGENT

Any substance, such as a base metal (iron) or the sulfide ion (S^{2-}), that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

RELIQUEFACTION (re-LICK-we-FACK-shun) RELIQUEFACTION

The return of a gas to the liquid state; for example, a condensation of chlorine gas to return it to its liquid form by cooling.

RESIDUAL CHLORINE RESIDUAL CHLORINE

The amount of free and/or available chlorine remaining after a given contact time under specified conditions.

ROTAMETER (RODE-uh-ME-ter) ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part of the float.

SAPROPHYTES (SAP-row-FIGHTS) SAPROPHYTES

Organisms living in dead or decaying organic matter. They help natural decomposition of the organic solids in water.

STERILIZATION (stare-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all living microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point.

TOTAL RESIDUAL CHLORINE TOTAL RESIDUAL CHLORINE

The amount of available chlorine remaining after a given contact time. The sum of the combined available residual chlorine and the free available residual chlorine. Also see RESIDUAL CHLORINE.

TRIHALOMETHANES (TRI-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resultant compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

Chapter 5. DISINFECTION

(Lesson 1 of 2 Lessons)

5.0 PURPOSE OF DISINFECTION

5.00 Making Water Safe for Consumption

Our single most important natural resource is water. Without water we could not exist. Unfortunately, safe water is becoming very difficult to find. In the past, safe water could be found in remote areas, but with population growth and related pollution of waters, there are very few natural waters left that are safe to drink without treatment of some kind.

Water is the universal solvent and therefore carries all types of dissolved materials. Water also carries biological life forms which can cause diseases. These water-borne pathogenic organisms are listed in Table 5.1. Most of these organisms and the diseases they transmit are no longer a problem in the United States due to proper water protection, treatment and monitoring. However, many developing regions of the world still experience serious outbreaks of various water-borne diseases.

One of the cleansing processes in the treatment of safe water is called disinfection. Disinfection is the selective destruction of pathogenic organisms. Don't confuse disinfection with sterilization. Sterilization is the complete destruction of all organisms. Sterilization is not necessary in water treatment and is also quite expensive.

5.01 Safe Drinking Water Laws

In the United States, the U.S. Environmental Protection Agency is responsible for setting drinking water standards and for insuring their enforcement. This agency sets federal regulations which all state and local agencies must enforce. The 1976 Primary Drinking Water Regulations contain specific maximum allowable levels of substances known to be hazardous to human health. In addition to describing maximum contaminant levels (MCLs), the 1976 Primary Drinking Water Regulations also give detailed instructions on what to do when you exceed the maximum contaminant level for a particular substance. In Table 5.2 you will find an example of the Primary Drinking Water Regulations for *COLIFORM*[1] bacteria which are supposed to be killed by disinfection. Table 5.3 lists the coliform samples required per population served.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.0A What are pathogenic organisms?

5.0B What is disinfection?

5.0C Drinking water standards are established by what agency of the United States government?

5.0D MCL stands for what words?

TABLE 5.1 PATHOGENIC ORGANISMS (DISEASES) TRANSMITTED BY WATER

Bacteria
- Salmonella (salmonellosis)
- Shigella (bacillary dysentery)
- Bacillus typhosus (typhoid fever)
- Salmonella paratyphi (paratyphoid)
- Vibrio cholerae (cholera)

Viruses
- Enterovirus
    - Poliovirus
    - Coxsackie Virus
    - Echo Virus
- Andenovirus
- Reovirus
- Infectious Hepatitis

Intestinal Parasites
- Entamoeba histolytica (amoebic dysentery)
- Giardia lamblia (giardiasis)
- Ascaris lumbricoides (giant roundworm)

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[1] *Coliform (COAL-i-form). A group of bacteria which are found in the intestine of warm blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhabit the intestines of warm blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.*

TABLE 5.2 MICROBIOLOGICAL STANDARDS[a]

Contaminant	Maximum Contaminant Level (MCL)	Monitoring Requirement — Surface Only or Combination	Check Sampling, Reporting, and Public Notice
Coliform Bacteria[b]	*MEMBRANE FILTER* Coliforms shall not exceed: 1 per 100 *mL*, mean of all samples per month, 4 per 100 *mL* in more than one sample if less than 20 samples collected per month, or, 4 per 100 *mL* in more than 5% of samples if 20 or more samples are examined per month. *FERMENTATION TUBE — 10 mL PORTION* Coliforms shall not be present in more than 10% of portions per month, Not more than 1 sample may have 3 or more portions positive when less than 20 samples are examined per month, or Not more than 5% of samples may have 3 or more portions positive when 20 or more samples are examined per month.	Regular time intervals, monthly rate based on population (Table 9.3).	If MCL is exceeded, report to state within 48 hours and notify public. *MEMBRANE FILTER* If a single sample exceeds 4 per 100 *mL*, initiate at least two consecutive daily check samples from one sampling point. Collect additional samples daily or as directed by the state until at least two consecutive daily check samples show less than 1 per 100 *mL*. If any check sample confirms the presence of coliform, report to the state within 48 hours. *FERMENTATION TUBE* If a single sample contains coliform in 3 or more 10 *mL* portions, initiate check sampling as above and continue until at least two consecutive daily check samples show no positive tubes. If any check sample confirms the presence of coliform report to state within 48 hours.

[a] See Chapter 22, "Drinking Water Regulations," and poster provided with this manual for more details.

[b] See Chapter 7, "Laboratory Procedures," for details on how to do the coliform bacteria tests (membrane filter (MF) and multiple-tube fermentation (MPN)).

5.1 FACTORS INFLUENCING DISINFECTION

5.10 pH

The pH of water being treated can alter the efficiency of disinfectants. Chlorine, for example, disinfects water much faster at a pH around 7.0 than at a pH over 8.0.

5.11 Temperature

Temperature conditions also influence the effectiveness of the disinfectant. The higher the temperature of the water, the more efficiently it can be treated. Water near 70 to 85°F (21 to 29°C) is easier to disinfect than water at 40 to 60°F (4 to 16°C). Longer contact times are required to disinfect water at lower temperatures. To speed up the process, operators often simply use larger amounts of chemicals. Where water is exposed to the atmosphere, the warmer the water temperature the greater the dissipation rate of chlorine into the atmosphere.

5.12 Turbidity

Under normal operating conditions, the turbidity level of water being treated is very low by the time the water reaches the disinfection process. Excessive turbidity will greatly reduce the efficiency of the disinfecting chemical or process. Studies in water treatment plants have shown that when water is filtered to a turbidity of one unit or less, most of the bacteria have been removed.

The suspended matter itself may also change the chemical nature of the water when the disinfectant is added. Some types of suspended solids can create a continuing demand for the chemical, thus changing the effective germicidal (germ killing) properties of the disinfectant.

5.120 Organic Matter

Organics found in the water can consume great amounts of disinfectants while forming unwanted compounds. *TRIHALOMETHANES*[2] are an example of undesirable compounds formed by reactions between chlorine and certain organics. Disinfecting chemicals often react with organics and *REDUCING AGENTS*[3] (Section 5.13). Then, if any of the chemical remains available after this initial reaction, it can act as an effective disinfectant. The reactions with organics and reducing agents, however, will have significantly reduced the amount of chemical available for this purpose.

5.121 Inorganic Matter

Inorganic compounds such as ammonia (NH_3) in the water being treated can create special problems. In the presence of ammonia, some oxidizing chemicals form side com-

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[2] *Trihalomethanes (TRI-HAL-o-METH-hanes). Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resultant compounds (THMs) are suspected of causing cancer.*

[3] *Reducing Agent. Any substance, such as a base metal (iron) or the sulfide ion (S^{2-}), that will easily donate (give up) electrons. The opposite is an oxidizing agent.*

TABLE 5.3 COLIFORM SAMPLES REQUIRED PER POPULATION SERVED

Population Served	Minimum Number of Samples per Month	Population Served	Minimum Number of Samples per Month
25 to 1,000	1[†]	90,001 to 96,000	95
1,001 to 2,500	2	96,001 to 111,000	100
2,501 to 3,300	3	111,001 to 130,000	110
3,301 to 4,100	4	130,001 to 160,000	120
4,101 to 4,900	5	160,001 to 190,000	130
4,901 to 5,800	6	190,001 to 220,000	140
5,801 to 6,700	7	220,001 to 250,000	150
6,701 to 7,600	8	250,001 to 290,000	160
7,601 to 8,500	9	290,001 to 320,000	170
8,501 to 9,400	10	320,001 to 360,000	180
9,401 to 10,300	11	360,001 to 410,000	190
10,301 to 11,100	12	410,001 to 450,000	200
11,101 to 12,000	13	450,001 to 500,000	210
12,001 to 12,900	14	500,001 to 550,000	220
12,901 to 13,700	15	550,001 to 600,000	230
13,701 to 14,600	16	600,001 to 660,000	240
14,601 to 15,500	17	660,001 to 720,000	250
15,501 to 16,300	18	720,001 to 780,000	260
16,301 to 17,200	19	780,001 to 840,000	270
17,201 to 18,100	20	840,001 to 910,000	280
18,101 to 18,900	21	910,001 to 970,000	290
18,901 to 19,800	22	970,001 to 1,050,000	300
19,801 to 20,700	23	1,050,001 to 1,140,000	310
20,701 to 21,500	24	1,140,001 to 1,230,000	320
21,501 to 22,300	25	1,230,001 to 1,320,000	330
22,301 to 23,200	26	1,320,001 to 1,420,000	340
23,201 to 24,000	27	1,420,001 to 1,520,000	350
24,001 to 24,900	28	1,520,001 to 1,630,000	360
24,901 to 25,000	29	1,630,001 to 1,730,000	370
25,001 to 28,000	30	1,730,001 to 1,850,000	380
28,001 to 33,000	35	1,850,001 to 1,970,000	390
33,001 to 37,000	40	1,970,001 to 2,060,000	400
37,001 to 41,000	45	2,060,001 to 2,270,000	410
41,001 to 46,000	50	2,270,001 to 2,510,000	420
46,001 to 50,000	55	2,510,001 to 2,750,000	430
50,001 to 54,000	60	2,750,001 to 3,020,000	440
54,001 to 59,000	65	3,020,001 to 3,320,000	450
59,001 to 64,000	70	3,320,001 to 3,620,000	460
64,001 to 70,000	75	3,620,001 to 3,960,000	470
70,001 to 76,000	80	3,960,001 to 4,310,000	480
76,001 to 83,000	85	4,310,001 to 4,690,000	490
83,001 to 90,000	90	More than 4,690,001	500

Source: EPA

[†] A community water system serving 25 to 1,000 persons, with written permission from the state, may reduce this sampling frequency, except that in no case shall it be reduced to less than one per quarter. The decision by the state will be based on a history of no coliform bacterial contamination for that system and on a sanitary survey by the state showing the water system to be supplied solely by a protected groundwater source; free of sanitary defects.

pounds causing a partial loss of disinfecting power. Silt can also create a chemical demand. It is clear, then, that the chemical properties of the water being treated can seriously interfere with the effectiveness of disinfecting chemicals.

5.13 Reducing Agents

Chlorine combines with a wide variety of materials, especially reducing agents. Most of the reactions are very rapid, while others are much slower. These side reactions complicate the use of chlorine for disinfection. The demand for chlorine by reducing agents must be satisfied before chlorine becomes available to accomplish disinfection. Examples of inorganic reducing agents present in water which will react with chlorine include hydrogen sulfide (H_2S), ferrous ion (Fe^{2+}), manganous ion (Mn^{2+}), and the nitrite ion (NO_2^-). Organic reducing agents in water also will react with chlorine and form chlorinated organic materials of potential health significance.

5.14 Microorganisms

5.140 Number and Types of Microorganisms

Microorganism concentration is important because the higher the number of microorganisms, the greater the demand for a disinfecting chemical. The resistance of microorganisms to specific disinfectants varies greatly. Non-spore-forming bacteria are generally less resistant than spore-forming bacteria. Cysts and viruses can be very resistant to certain types of disinfectants.

5.141 Removal Processes

Pathogenic organisms can be removed from water or killed by various physical and chemical water treatment processes. These processes are:

1. *COAGULATION.* Chemical coagulation followed by sedimentation and filtration will remove 90 to 95 percent of the pathogenic organisms, depending on which chemicals are used. Alum usage can increase virus removals up to 99 percent.
2. *SEDIMENTATION.* Properly designed sedimentation processes can effectively remove 20 to 70 percent of the pathogenic microrganisms. This removal is accomplished by allowing the pathogenic organisms (as well as non-pathogenic organisms) to settle out by gravity, assisted by chemical floc.
3. *FILTRATION.* Filtering water through granular filters is an effective means of removing pathogenic and other organisms from water. The removal rates vary from 20 to 99+ percent depending on the coarseness of the filter media and the type and effectiveness of pretreatment.
4. *DISINFECTION.* Disinfection chemicals such as chlorine are added to water to kill pathogenic microorganisms.

In chapter 4 you have studied the first three processes. The fourth, disinfection, is the subject of this chapter.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.1A How does temperature of the water influence disinfection?

5.1B How does pH influence the effectiveness of disinfection?

5.1C What influence do microorganisms have on disinfection?

5.2 PROCESS OF DISINFECTION

5.20 Purpose of Process

The purpose of disinfection is to destroy harmful organisms. This can be accomplished either physically or chemically. Physical methods may (1) physically remove the organisms from the water or (2) introduce motion that will disrupt the cells' biological activity and kill them.

Chemical methods alter the cell chemistry causing the microorganism to die. The most widely used disinfectant chemical is chlorine. Chlorine is easily obtained, relatively cheap, and most importantly, leaves a *RESIDUAL CHLORINE*[4] that can be measured. Other disinfectants are also used. There has been increased interest in disinfectants other than chlorine because of the *CARCINOGENIC*[5] compounds that chlorine may form (TRIHALOMETHANES or THMs).

This chapter will focus primarily on the use of chlorine as a disinfectant. However, let's take a brief look first at other disinfectant methods and chemicals. Some of these are being more widely applied today because of the potential adverse side effects of chlorination.

5.21 Agents of Disinfection

5.210 Physical Means of Disinfection

A. *ULTRAVIOLET RAYS* can be used to destroy pathogenic microorganisms. To be effective, the rays must come in contact with each microorganism. The ultraviolet energy disrupts various organic components of the cell causing a biological change that is fatal to the microorganisms.

This system has not had widespread acceptance because of the lack of measurable residual and the cost of operation. Currently, use of ultraviolet rays is limited to small or local systems and industrial applications. Ocean-going ships have used these systems for their water supply.

B. *HEAT* has been used for centuries to disinfect water. Boiling water for about 15 minutes will destroy essentially all microorganisms. This method is very energy intensive and thus very expensive. The only practical application is in the event of a disaster when individual local users are required to boil their water.

C. *ULTRASONIC WAVES* have been used to disinfect water on a very limited scale. Sonic waves destroy the microorganism by vibration. This procedure is not yet practical and is very expensive.

5.211 Chemical Disinfectants (Other Than Chlorine)

A. *IODINE* has been used as a disinfectant in water since 1920, but its use has been limited to emergency treatment of water supplies. Although it has long been recognized as a good disinfectant, iodine's high cost and potential physiological effects (pregnant women can suffer serious side effects) have prevented widespread acceptance. The recommended dosage is two drops of iodine (tincture of iodine which is 7 percent available iodine) in a liter of water.

B. *BROMINE* has been used only on a very limited scale for water treatment because of its handling difficulties. Bromine causes skin burns on contact. Because bromine is a very reactive chemical, residuals are hard to obtain. This also limits its use. Bromine can be purchased at swimming pool supply stores.

C. *BASES* such as sodium hydroxide and lime can be effective disinfectants but the high pH leaves a bitter taste in the finished water. Bases can also cause skin burns when left too long in contact with the skin. Bases effectively kill all microorganisms (they sterilize rather than just disinfect water). Although this method has not been used on a large scale, bases have been used to sterilize water pipes.

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[4] *Residual Chlorine. The amount of free and/or available chlorine remaining after a given contact time under specified conditions.*

[5] *Carcinogen (car-SIN-o-jen). Any substance which tends to produce a cancer in an organism.*

D. *OZONE* has been used in the water industry since the early 1900s, particularly in France. In the United States it has been used primarily for taste and odor control. The limited use in the United States has been due to its high costs, lack of residual, difficulty in storing and maintenance requirements.

Although ozone is effective in disinfecting water, its use is limited by its solubility. The temperature and pressure of water being treated regulate the amount of ozone that can be dissolved in the water. These factors tend to limit the disinfectant strength that can be made available to treat the water.

Many scientists claim that ozone destroys all microorganisms. Unfortunately, significant residual ozone does not guarantee that a water is safe to drink. Organic solids may protect organisms from the disinfecting action of ozone and increase the amount of ozone needed for disinfection.

In addition, ozone residuals cannot be maintained in metallic conduits for any period of time because of ozone's reactive nature. The inability of ozone to provide a residual in the distribution system is a major drawback to its use. However, recent information about the formation of trihalomethanes by chlorine compounds has resulted in renewed interest in ozone as an alternative means of disinfection.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.2A List the physical agents that have been used for disinfection other than chlorine.

5.2B List the chemical agents that have been used for disinfection other than chlorine.

5.2C What is a major limitation to the use of ozone?

5.22 Chlorine (Cl_2)

5.220 Properties of Chlorine

Chlorine is a greenish-yellow gas with a penetrating and distinctive odor. The gas is two-and-a-half times heavier than air. Chlorine has a very high coefficient of expansion. If there is a temperature increase of 50°F (28°C) (from 35°F to 85°F or 2°C to 30°C), the volume will increase from 84 to 89 percent. This expansion could easily rupture a cylinder or line full of liquid chlorine. For this reason all chlorine containers must not be filled to more than 85 percent of their volume. One liter of liquid chlorine can evaporate and produce 450 liters of chlorine gas.

Chlorine by itself is non-flammable and non-explosive, but it will support combustion. When the temperature rises, so does the vapor pressure of chlorine. This means that when the temperature increases, the pressure of the chlorine gas inside a chlorine container will increase. This property of chlorine must be considered when:

1. Feeding chlorine gas from a container, and
2. Dealing with a leaking chlorine cylinder.

5.221 Chlorine Disinfection Action

The exact mechanism of chlorine disinfection action is not fully known. One theory holds that chlorine exerts a direct action against the bacterial cell, thus destroying it. Another theory is that the toxic character of chlorine inactivates the *ENZYMES*[6] which enable living microorganisms to use their food supply. As a result, the organisms die of starvation. From the point of view of water treatment, the exact mechanism of chlorine disinfection is less important than its demonstrated effects as a disinfectant.

When chlorine is added to water, several chemical reactions take place. Some involve the molecules of the water itself, and some involve organic and inorganic substances suspended in the water. We will discuss these chemical reactions in more detail in the next few sections of this chapter. First, however, there are some terms associated with chlorine disinfection that you should understand.

When chlorine is added to water containing organic and inorganic materials, it will combine with these materials and form chlorine compounds. If you continue to add chlorine, you will eventually reach a point where the reaction with organic and inorganic materials stops. At this point, you have satisfied what is known as the *"CHLORINE DEMAND."*

The chemical reactions between chlorine and these organic and inorganic substances produce chlorine compounds. Some of these compounds have disinfecting properties; others do not. In a similar fashion, chlorine reacts with the water itself and produces some substances with disinfecting properties. The total of all the compounds with disinfecting properties *PLUS* any remaining free (uncombined) chlorine is known as the *"CHLORINE RESIDUAL."* The presence of this measurable chlorine residual is what indicates to the operator that all possible chemical reactions have taken place and that there is still sufficient *"AVAILABLE RESIDUAL CHLORINE"* to kill the microorganisms present in the water supply.

Now, if you add together the amount of chlorine needed to satisfy the chlorine demand and the amount of chlorine residual needed for disinfection, you will have the *"CHLORINE DOSE."* This is the amount of chlorine you will have to add to the water to disinfect it.

Chlorine Dose, mg/*L* = Chlorine Demand, mg/*L* + Chlorine Residual, mg/*L*

where

Chlorine Residual, mg/*L* = Combined Chlorine Forms, mg/*L* + Free Chlorine, mg/*L*

5.222 Reaction with Water (Hydrolysis[7])

Free chlorine combines with water to form hypochlorous and hydrochloric acids:

$$\text{Chlorine} + \text{Water} \rightleftharpoons \text{Hypochlorous Acid} + \text{Hydrochloric Acid}$$

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$$

---

[6] *Enzymes (En-zimes). Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.*

[7] *Hydrolysis (hi-DROLL-uh-sis). A chemical reaction in which a compound is converted into another compound by taking up water.*

Depending on the pH, hypochlorous acid may be presnt in the water as the hydrogen ion and hypochloriate ion (Figure 5.1).

Hypochlorous Acid ⇌ Hydrogen Ion + Hypochlorite Ion

$$HOCl \rightleftharpoons H^+ + OCl^-$$

In solutions that are dilute (low concentration of chlorine) and have a pH above 4, the formation of HOCl (hypochlorous acid) is most complete and leaves little free chlorine (Cl_2) existing. The hypochlorous acid is a weak acid and hence is poorly dissociated (broken up into ions) at pH levels below 6. Thus any free chlorine or hypochlorite (OCl^-) added to water will immediately form either HOCl or OCl^-, the species formed is thereby controlled by the pH value of the water. This is extremely important since HOCl and OCl^- differ in disinfection ability. HOCl has a much greater disinfection potential than OCl^-. Normally in water with a pH of 7.3, 50 percent of the chlorine present will be in the form of HOCl and 50 percent in the form of OCl^-. The higher the pH level, the greater the percent of OCl^-.

5.223 Reaction with Impurities in Water

Most waters that have been processed still contain some impurities. In this section we will discuss some of the more common impurities that react with chlorine and we will examine the effects of these reactions on the disinfection ability of chlorine.

A. Hydrogen sulfide (H_2S) and ammonia (NH_3) are two inorganic substances that may be found in water when it reaches the disinfection stage of treatment. Their presence can complicate the use of chlorine for disinfection purposes. This is because hydrogen sulfide and ammonia are what is known as *REDUCING AGENTS*. That is, they give up electrons easily. Chlorine reacts rapidly with these particular reducing agents producing some undesirable results.

Hydrogen sulfide produces an odor which smells like rotten eggs. It reacts with chlorine to form sulfuric acid and elemental sulfur (depending on temperature, pH and hydrogen sulfide concentration). Elemental sulfur is objectionable because it can cause odor problems and will precipitate as finely divided white particles which are sometimes colloidal in nature.

The chemical reactions between hydrogen sulfide and chlorine are as follows:

Hydrogen Sulfide + Chlorine + Oxygen Ion → Elemental Sulfur + Water + Chloride Ions

$$H_2S + Cl_2 + O^{2-} \rightarrow S\downarrow + H_2O + 2\,Cl^-$$

The chlorine required to oxidize hydrogen sulfide to sulfur and water is 2.08 mg/*L* chlorine to 1 mg/*L* hydrogen sulfide. The complete oxidation of hydrogen sulfide to the sulfate form is as follows:

Hydrogen Sulfide + Chlorine + Water → Sulfuric Acid + Hydrochloric Acid

$$H_2S + Cl_2 + 4\,H_2O \rightarrow H_2SO_4 + HCl$$

Thus, 8.32 mg/*L* of chlorine are required to oxidize one mg/*L* of hydrogen sulfide to the sulfate form. Note that in both reactions the chlorine is converted to the chloride ion (Cl^- or HCl) which has no disinfecting power nor produces any chlorine residual. In waterworks practice we always chlorinate to produce a chlorine residual, therefore the second reaction (complete oxidation of hydrogen sulfide) occurs before we have any chlorine residual in the water we are treating.

When chlorine is added to water containing ammonia (NH_3), it reacts rapidly with the ammonia and forms *CHLORAMINES*[8]. This means that less chlorine is available to act as a disinfectant. As the concentration of ammonia increases, the disinfectant power of the chlorine drops off at a rapid rate.

B. When organic materials are present in water being disinfected with chlorine, the chemical reactions that take place may produce suspected carcinogenic compounds (trihalomethanes). The formation of these compounds can be prevented by limiting the amount of prechlorination and by removing the organic materials prior to chlorination of the water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.2D List two inorganic reducing chemicals that react rapidly with chlorine.

5.2E How is the chlorine demand determined?

5.2F How is the chlorine dosage determined?

5.23 Hypochlorite (OCl)

5.230 Reactions with Water

The use of hypochlorite to treat potable water achieves the same result as chlorine gas. Hypochlorite may be applied in the form of calcium hypochlorite ($Ca(OCl)_2$) or sodium hypochlorite (NaOCl). The form of calcium hypochlorite most frequently used to disinfect water is known as **High Test Hypochlorite** (*HTH*). The chemical reactions of hypochlorite in water are similar to those of chlorine gas.

CALCIUM HYPOCHLORITE

Calcium Hypochlorite + Water → Hypochlorous Acid + Calcium Hydroxide

$$Ca(OCl)_2 + 2\,H_2O \rightarrow 2\,HOCl + Ca(OH)_2$$

SODIUM HYPOCHLORITE

Sodium Hypochlorite + Water → Hypochlorous Acid + Sodium Hydroxide

$$NaOCl + H_2O \rightarrow HOCl + Na(OH)$$

Calcium hypochlorite (HTH) is used by a number of small water supply systems. A problem occurs in these systems when sodium fluoride is injected at the same point as the hypochlorite. A severe crust is formed when the calcium and fluoride ions combine.

5.231 Differences Between Chlorine Gas and Hypochlorite Compound Reactions

The only difference between the reactions of the hypochlorite compounds and chlorine gas is the "side" reactions of the end products. The reaction of chlorine gas tends to

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[8] *Chloramines (KLOR-uh-means). Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.*

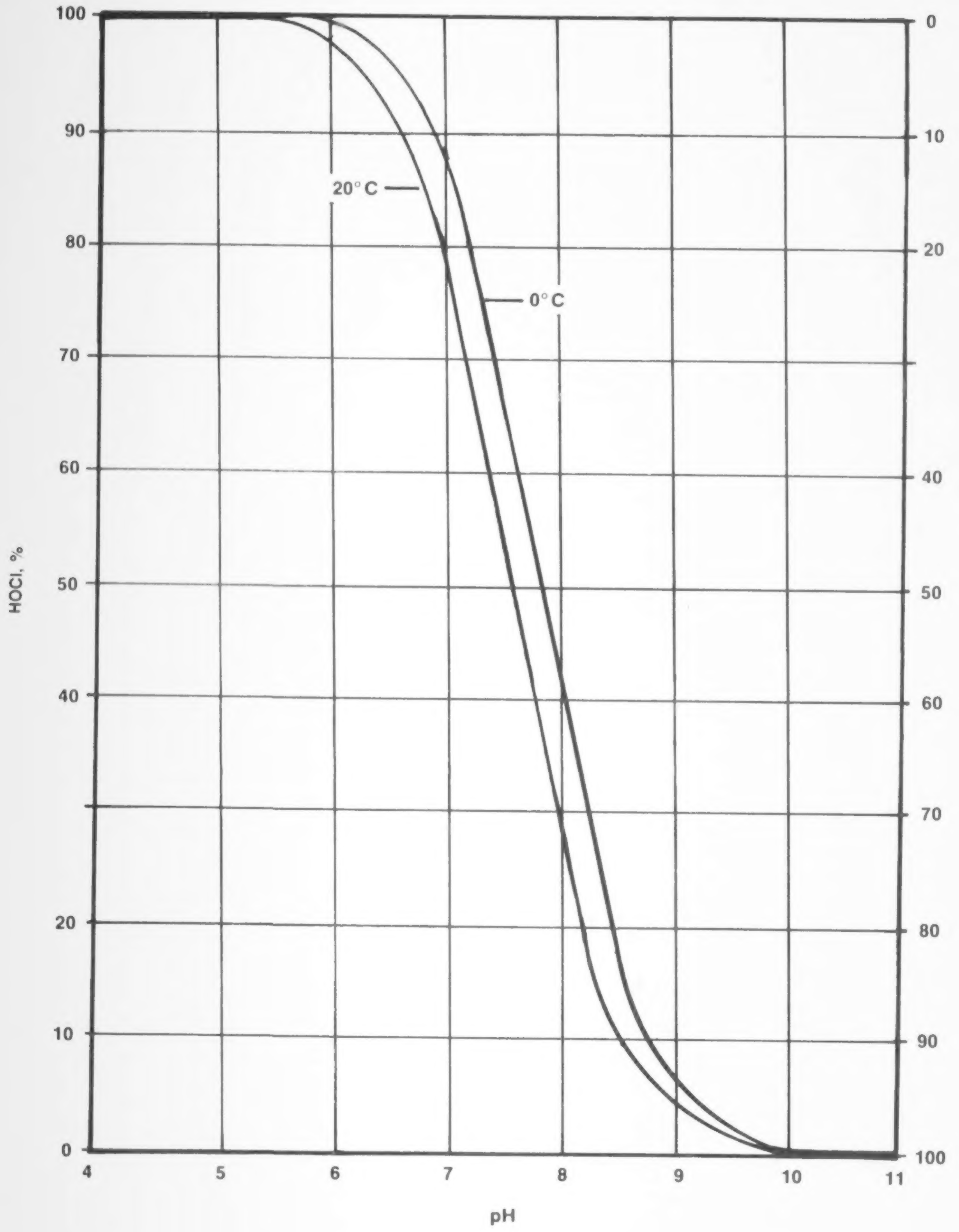

Fig 5.1 Relationship between hypochlorous acid (HOCl), hypochlorite ion (OCl⁻) and pH

lower the pH (increases the hydrogen ion (H^+) concentration) by the formation of hydrochloric acid which favors the formation of hypochlorous acid (HOCl). The hypochlorite tends to raise the pH with the formation of hydroxyl ions (OH^-) from the calcium or sodium hydroxide. At a high pH of around 8.5 or higher, the hypochlorous acid (HOCl) is almost completely dissociated to the ineffective hypochlorite ion (OCl^-) (Figure 5.1). This reaction also depends on the *BUFFER CAPACITY*[9] (amount of bicarbonate, HCO_3^-, present) of the water.

$$\begin{array}{ccccc} \text{Hypochlorous} & \rightleftharpoons & \text{Hydrogen} & + & \text{Hypochlorite} \\ \text{Acid} & & \text{Ion} & & \text{Ion} \end{array}$$

$$HOCl \rightleftharpoons H^+ + OCl^-$$

5.24 Chlorine Dioxide (ClO_2)

5.240 Reaction in Water

Chlorine dioxide may be used as a disinfectant. Chlorine dioxide does not form carcinogenic compounds that may be formed by other chlorine compounds. Also it is not affected by ammonia, and is a very effective disinfectant at higher pH levels. In addition, chlorine dioxide reacts with sulfide compounds, thus helping to remove them and eliminate their characteristic odors. Phenolic tastes and odors can be controlled by using chlorine dioxide.

Chlorine dioxide reacts with water to form chlorate and chlorite ions in the following manner:

$$\begin{array}{ccccccccc} \text{Chlorine} & + & \text{Water} & \rightarrow & \text{Chlorate} & + & \text{Chlorite} & + & \text{Hydrogen} \\ \text{Dioxide} & & & & \text{Ion} & & \text{Ion} & & \text{Ions} \end{array}$$

$$2\,ClO_2 + H_2O \rightarrow ClO_3^- + ClO_2^- + 2\,H^+$$

5.241 Reactions with Impurities in Water

A. *INORGANIC COMPOUNDS*

Chlorine dioxide is an effective *OXIDIZING AGENT*[10] with iron and manganese and does not leave objectionable tastes or odors in the finished water. Because of its oxidizing ability, chlorine dioxide usage must be monitored and the dosage will have to be increased when treating waters with iron and manganese.

B. *ORGANIC COMPOUNDS*

Chlorine dioxide does not react with organics in water. Therefore, there is little danger of the formation of potentially dangerous trihalomethanes.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.2G How does pH influence the relationship between HOCl and OCl^-?

5.2H How does chlorine gas and hypochlorite influence pH?

5.25 Breakpoint Chlorination[11]

In determining how much chlorine you will need for disinfection, remember you will be attempting to produce a certain chlorine residual in the form of *FREE AVAILABLE RESIDUAL CHLORINE*[12]. Chlorine in this form has the highest disinfecting ability. *BREAKPOINT CHLORINATION* is the name of this process of adding chlorine to water until the chlorine demand has been satisfied. Further additions of chlorine will result in a chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Public water supplies are normally chlorinated *PAST THE BREAKPOINT*.

Take a moment here to look at the breakpoint chlorination curve in Figure 5.2. Assume the water being chlorinated contains some manganese, iron, nitrate, organic matter and ammonia. Now add a small amount of chlorine. The chlorine reacts with (oxidizes) the manganese, iron and nitrite. That's all that happens — no disinfection and no chlorine residual (Figure 5.2, points 1 and 2). Add a little more chlorine, enough to react with the organics and ammonia; *CHLORORGANICS*[13] and *CHLORAMINES*[14] will form. The chloramines produce a combined chlorine residual — a chlorine residual combined with other substances so it has lost some of its disinfecting strength. Combined residuals have rather poor disinfecting power and may cause tastes and odors (points 1 to 3).

With just a little more chlorine the chloramines and some of the chlororganics are destroyed (points 3 to 4). Adding just one last amount of chlorine we get *FREE AVAILABLE RESIDUAL CHLORINE* (beyond point 4) — free in the sense that it has not reacted with anything and available in that it *CAN* and *WILL* react if need be. Free available residual chlorine is the best residual for disinfection. It disinfects faster and without the "swimming pool" odor of combined residual chlorine. Free available residual chlorine begins to form at the breakpoint; the process is called *BREAKPOINT CHLORINATION*. In water treatment plants today it is common practice to go "past the breakpoint." This means that the treated water will have a low chlorine residual, but the residual will be a very effective disinfectant because it is in the form of *FREE AVAILABLE RESIDUAL CHLORINE*.

Let's look more closely at some of the chemical reactions that take place during chlorination. When chlorine is added to waters containing ammonia (NH_3), the ammonia reacts with hypochlorous acid (HOCl) to form monochloramine, dichloramine and trichloramine. The formation of these chloramines depends on the pH of the solution and the initial chlorine-ammonia ratio.

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[9] *Buffer Capacity. A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.*

[10] *Oxidizing Agent. Any substance, such as oxygen (O_2) and chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a reducing agent.*

[11] *Breakpoint Chlorination. The addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.*

[12] *Free Available Residual Chlorine. That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.*

[13] *Chlororganic (chlor-or-GAN-nick). Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.*

[14] *Chloramines (KLOR-uh-means). Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.*

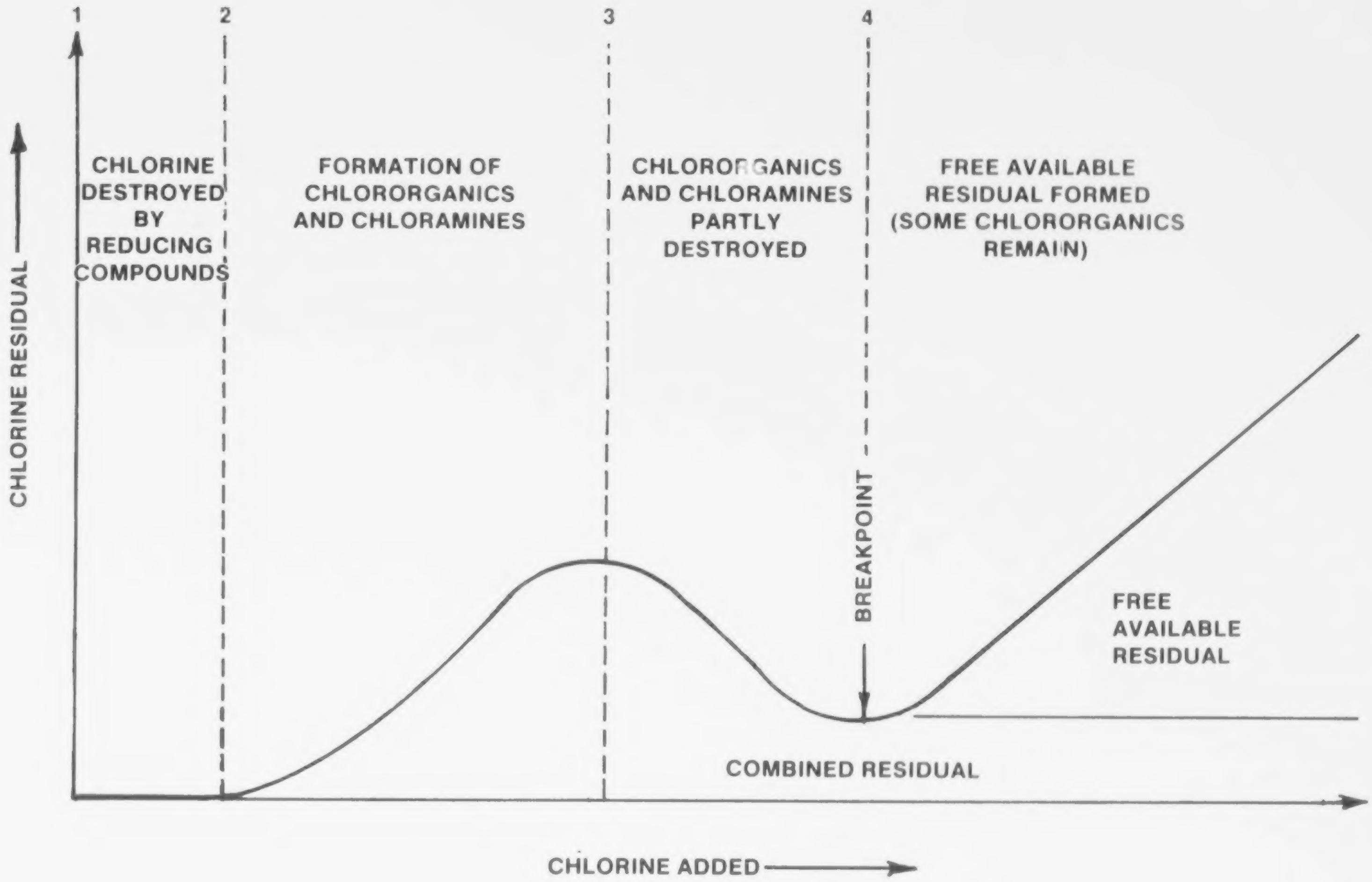

Fig. 5.2 Breakpoint chlorination curve

Ammonia + Hypochlorous Acid → Chloramine + Water

$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$ Monochloramine

$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$ Dichloramine

$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$ Trichloramine[15]

At the pH levels that are usually found in water (pH 6.5 to 9.5), monochloramine and dichloramine exist together. At pH levels below 5.5, dichloramine exists by itself. Below pH 4.0, trichloramine is the only compound found. The mono- and dichloramine forms have definite disinfection powers and are of interest in the measurement of chlorine residuals. Dichloramine has a more effective disinfecting power than monochloramine. However, dichloramine is not recommended as a disinfectant because of taste and odor problems. Chlorine reacts with *PHENOL*[16] and salicylic acid (both are leached into water from leaves and blossoms) to form *CHLOROPHENOL*[17] which has an intense medicinal odor. This reaction goes much slower in the presence of monochloramine.

Historically some plants add ammonia (aqua ammonia) to the filter effluent when they chlorinated (postchlorination) to produce chloramines. The reason for this practice was that chloramines produced very long lasting chlorine residuals. Today plants are considering adding ammonia because chloramines do not form trihalomethanes. A major limitation of using chloramine residuals is the fact that chloramines are not as effective as a disinfectant as free chlorine residuals. Another potential problem is that chloramines may cause tastes and odors in the treated water. Studies have indicated a dosage of three parts chlorine to one part ammonia (3:1) will form monochloramines. Monochloramines form combined residual chlorine (rising part of breakpoint curve in Figure 5.2) and apparently do not produce tastes and odors. Dichloramines form during the oxidation of combined residual materials (Figure 5.2) and will cause tastes and odors. Trichloramines are formed past the breakpoint and also may form tastes and odors. Although chloramines are non-toxic to healthy humans, they can have a debilitating (weakening) effect on individuals with renal disease and who must undergo kidney dialysis.

In plants where triahalomethanes (THMs) are not a problem, sufficient chlorine is added to the raw water (prechlorination) to go "past the breakpoint." The chlorine residual will aid coagulation, control algae problems in basins, reduce odor problems in treated water, and provide sufficient chlorine contact time for an effective kill of pathogenic organisms. Therefore the treated water will have a very low chlorine residual, but the residual will be a very effective disinfectant.

5.26 Critical Factors

Both *CHLORINE RESIDUAL* and *CONTACT TIME* are essential for effective killing of pathogenic microorganisms. Complete initial mixing is very important. Changes in pH affect the disinfection ability of chlorine and you must reexamine the best combination of contact time and chlorine residual when the pH fluctuates. Critical factors influencing disinfection are summarized as follows:

1. Injection point and method of mixing to get disinfectant in contact with water being disinfected. Depends on whether using prechlorination or postchlorination.
2. Contact time. With good initial mixing, the longer the contact time, the better the disinfection.
3. Effectiveness of upstream treatment processes. The lower the turbidity (suspended solids, organic content, reducing agents) of the water, the better the disinfection.
4. Temperature. The higher the temperature, the more rapid the rate of disinfection.
5. Dosage and type of chemical. Usually the higher the dosage, the quicker the disinfection rate. The form (chloramines or free chlorine residual) and type of chemical also influences the disinfection rate.
6. pH. The lower the pH, the better the disinfection.

5.3 POINTS OF APPLICATION

5.30 Wells and Pumps[18]

5.300 Disinfecting New and Existing Wells

When a new well is completed, it is necessary to disinfect the well, pump and screen. A 50 mg/*L* residual of free chlorine in contact with all surfaces of the well, screen, pump and piping is recommended. Consideration must be given to the fact that the water aquifer could have been contaminated during the drilling process. Disinfection is usually accomplished by using a chlorine solution applied into the well and the aquifer around the well.

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[15] *More commonly called nitrogen trichloride.*

[16] *Phenol (FEE-noll). Organic compounds that are derivatives of benzene.*

[17] *Chlorophenol (klor-o-FEE-noll). Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.*

[18] *Also see Section 3.5, "Disinfection of Wells and Pumps" in Chapter 3.*

To accomplish this process the use of sodium hypochlorite is recommended. As previously mentioned, 50 mg/*L* is needed and 24 hours of contact time is recommended. At the end of this period, pump the well until all evidence of a chlorine residual is gone. Then take a sample and test for *TOTAL COLIFORMS*[19] to determine the effectiveness of the chlorine dosage.

Since organic matter such as oil may be used during drilling, the chlorine solution should have a concentration of about 1,000 mg/*L* before being injected into the well through the vent pipe. If the chlorine solution is applied to the well by injecting the chlorine through the pump column pipe, a chlorine dosage of 100 mg/*L* is acceptable. By using the column pipe, the oil on the water surface is avoided and the large amount of chlorine is not needed.

5.301 Sample Problem

FORMULAS

To disinfect a well, the first step is to determine the volume of water in the well. There are three approaches to calculating the volume of water in a well.

1. Calculate the volume of water using the diameter of the casing and the depth of water.

$$\text{Volume, gal} = \frac{(0.785)(\text{Diameter, in})^2(\text{Depth, ft})(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}$$

2. When the depth of water in a well changes from time to time, many operators calculate a constant for their well in terms of gallons of water per foot of water in the well.

$$\text{Volume, gal/ft} = \frac{(0.785)(\text{Diameter, in})^2(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}$$

3. Sometimes tables are available which allow you to find the volume in gallons per foot from the table if you know the diameter of the casing.

To find the pounds of chlorine needed to disinfect a well, we need to know the volume of water in gallons and the desired chlorine dose in milligrams per liter. Convert the volume in gallons to million gallons by dividing by 1,000,000.

$$\text{Volume, M Gal} = \frac{(\text{Volume, Gal})\ (1\text{ Million})}{1{,}000{,}000}$$

$$\boxed{\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})}$$

We can "prove" the above formula if we know that one liter of water weighs 1,000,000 mg.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})\left(\frac{\text{Dose, mg}}{1{,}000{,}000\text{ mg}}\right)(8.34\text{ lbs/gal})$$

Note that the dose is now in milligrams per million milligrams, or parts per million. Now change the milligrams to pounds so we will have dose, pounds chlorine per million pounds of water.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})\left(\frac{\text{Dose, lbs}}{\text{M lbs}}\right)(8.34\text{ lbs/gal})$$

To calculate the gallons of sodium hypochlorite needed to disinfect a well, we need to know the pounds of chlorine needed and the percent available chlorine in the hypochlorite.

$$\begin{array}{c}\text{Sodium Hypochlorite}\\ \text{Solution, gallons}\end{array} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\text{ lbs/gal})(\text{Hypochlorite, }\%)}$$

EXAMPLE 1

A 200-foot deep new well is to be disinfected with a five percent sodium hypochlorite solution. The top 150 feet of the well has a 12-inch casing and the bottom 50 feet has an 8-inch casing and well screen. The water level in the well is at 80 feet from the top of the well. Since this is a new well, the desired chlorine concentration in the initial dose should be 100 mg/*L*. How many gallons of five percent sodium hypochlorite will be needed?

	Known	Unknown
Depth of Well, ft	= 200 ft	5% Hypochlorite, gallons
Hypochlorite, %	= 5%	
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Top 150 ft	= 12-in casing	
Bottom 50 ft	= 8-in casing and screen	
Water, level, ft	= 80 ft from top or = 120 ft from bottom	

1. Find the volume of water in the well. Use Table 5.4

TABLE 5.4 VOLUME OF WATER IN WELL PER FOOT OF DEPTH

Casing Size, in	Volume, gallons per foot of depth
4	0.65
5	1.02
6	2.47
8	2.61
10	4.08
12	5.87
14	7.99
16	10.44
18	13.21
20	16.31

a. From 80 feet from top to 150 feet from top we have 70 feet (150-ft − 80 ft) of 12-inch casing.

From Table 5.4, 12-inch casing has 5.87 gallons of water per foot.

b. From 150 feet from top to 200 feet from top we have 50 feet (200 ft − 150 ft) of 8 in-inch casing.

From Table 5.4, 8-inch casing has 2.61 gallons of water per foot.

$$\begin{aligned}\begin{array}{c}\text{Total Volume of}\\ \text{Water, gallons}\end{array} &= (\text{Length, ft})(\text{Volume, gal/ft})\\ &= (70\text{ ft})(5.87\text{ gal/ft}) + (50\text{ ft})(2.61\text{ gal/ft})\\ &= 411\text{ gal} + 131\text{ gal}\\ &= 542\text{ gallons of water}\end{aligned}$$

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[19] *Total Coliforms. See procedures for Coliform Test in Chapter 7, "Laboratory Procedures."*

If Table 5.4 was not available, we could calculate the approximate volume in gallons per foot of depth and the total volume of water in gallons.

a. For the 12-inch casing, calculate the volume in gallons per foot of depth.

$$\text{Volume, gal} = (\text{Area, sq ft})(\text{Depth, ft})(7.48\ \text{gal/cu ft})$$

$$= (\text{Area, sq ft})(7.48\ \text{gal/cu ft})(\text{Depth, ft})$$

$$\text{Volume, gal/ft} = (\text{Area, sq ft})(7.48\ \text{gal/cu ft})$$

$$= \frac{(0.785)(12\ \text{in})^2(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$= 5.87\ \text{gal/ft}$$

b. For the 8-inch casing, calculate the volume in gallons per foot of depth.

$$\text{Volume, gal/ft} = (\text{Area, sq ft})(7.48\ \text{gal/cu ft})$$

$$= \frac{(0.785)(8\ \text{in})^2(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$= 2.61\ \text{gal/ft}$$

$$\begin{array}{c}\text{Total Volume of} \\ \text{Water, gallons}\end{array} = (\text{Length, ft})(\text{Volume, gal/ft})$$

$$= (70\ \text{ft})(5.87\ \text{gal/ft}) + (50\ \text{ft})(2.61\ \text{gal/ft})$$

$$= 411\ \text{gal} + 131\ \text{gal}$$

$$= 542\ \text{gallons of water}$$

This answer is the same as the 542 gallons we obtained using the values in Table 5.4.

2. Find the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Vol Water, M Gal})(\text{Chlorine Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.000542\ \text{M Gal})(100\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 0.45\ \text{lbs chlorine}$$

3. Calculate the gallons of 5 percent sodium hypochlorite solution needed.

$$\begin{array}{c}\text{Sodium Hypochlorite} \\ \text{Solution, gallons}\end{array} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(0.45\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5\%)}$$

$$= 1.08\ \text{gallons}$$

A little over one gallon of 5 percent solution sodium hypochlorite should do the job.

The gravel in a gravel envelope well must be disinfected as the gravel is added to the well. This is accomplished by adding half a pound (227 gm) of five gram *HTH*[20] granules per ton of gravel.

When disinfecting a well that draws from more than one aquifer, remember that there is nearly always flow from one aquifer to another. Also if water is flowing through a well, the procedures described in this chapter may not work very well because the flowing water will carry away the chlorine.

Once water from a well starts producing positive coliform test results, it is almost impossible to correct the problem with chlorine treatment. However, some wells will clear up after long periods of pumping (sometimes two years are required).

Disinfection of the well may not be accomplished the first time so this procedure may have to be repeated a second and even possibly a third time.

PROCEDURES

5.302 *Procedures*

Procedures described in this section are one method for disinfecting a well; however, other methods are available and may be used.

a. Calculate volume of water in well using guidelines in Example 1.

b. Wash the pump column or drop pipe (pipe attached to the pump) with chlorine solution as it is lowered into well. The chlorine solution can be fed through a hose to wash the pipe.

c. After the chlorine solution has been fed into the well, operate the pump so as to thoroughly mix the disinfectant with the water in the well. Pump until the water discharged has the odor of chlorine. Then shutdown pump and let water surge back down into well. Repeat this procedure several times over an hour.

d. Allow the well to stand for 24 hours.

e. Pump well to waste until all traces of chlorine are gone.

f. Take a bacteriological sample for analysis. Use the 24-hour membrane filter method for the quickest results.

g. If results of bacteriological analysis for total coliforms indicate unsafe conditions, repeat disinfection procedure. Conditions are considered unsafe when the test results are positive (there are coliforms present).

5.303 *Continuous Disinfecting of Wells*

Normally wells are treated by a single application of disinfecting solution, but since more and more groundwater sources are becoming contaminated, it is becoming a standard practice to disinfect groundwaters on a continuous basis.

The type of disinfection installation to be used will depend on which type of chemicals are to be used. From a safety standpoint the use of hypochlorite is the safest. Normally there are fewer hazards associated with hypochlorite compounds than with liquid or gaseous chlorine. However, liquid or gaseous chlorine is cheaper to use than hypochlorite, especially if large volumes of chlorine are required.

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[20] *HTH. High Test Hypochlorite. Calcium hypochlorite or Ca(OCl$_2$).*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.3A When disinfecting a well, why should the well, pump, screen and aquifer around the well all be disinfected?

5.3B Where should the chlorine be applied to a well being disinfected?

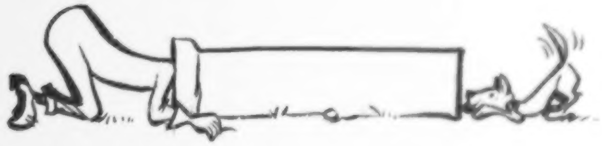
5.3C How would you determine if a well has been successfully disinfected?

5.31 Mains

5.310 Procedures

A. Preventive Measures

One of the most effective steps in disinfecting water mains is to do everything possible to prevent the mains from becoming contaminated. Keep as much outside material such as dirt, construction materials, animals, rodents and dirty water out of mains being installed or repaired. Inspect the interior of all pipes for cleanliness as the main is laid in the trench. Keep the trenches dry or dewatered. Install watertight plugs in all open-end joints whenever the trench is unattended for any length of time. An exception to the use of watertight plugs in the open ends of joints is when groundwater could cause the pipe to float. When a long pipeline is to be laid, a dry trench may not always be possible during the night when crews are not on duty.



B. Preliminary Measures

Flush the mains before attempting to disinfect them. Flushing is not an alternative to cleanliness when laying or repairing mains. Flushing cannot be expected to remove debris caked on joints, crevices and other parts of the system. Flush the mains using water flowing with a velocity of at least 2.5 ft/sec (0.75 m/sec). See Table 5.5 for flows required in gallons per minute (GPM) to flush various diameter mains with 2.5 ft/sec and 5.0 ft/sec flushing velocities.

Special care must be exercised to be sure fittings and valves are clean before disinfecting a main. Also, all air pockets or other conditions which would prevent proper disinfection should be eliminated. Many water mains contain mechanical joints. These joints have spaces that are difficult to chlorinate once they become filled with water. This is one reason why initial flushing may be ineffective. Some operators crush calcium hypochlorite tablets and place the crushed tablets in joints to improve the disinfection process.

TABLE 5.5 FLOWS REQUIRED FOR VARIOUS FLUSHING VELOCITIES

Line Size, Inches	Flow Required, GPM[a] Velocity, 2.5 ft/sec	Velocity, 5 ft/sec
4	100	200
6	220	440
8	390	780
10	610	1,220
12	880	1,760
14	1,200	2,400
16	1,570	3,140

[a] Line should be flushed for at least 30 minutes.

If you wish to calculate the flow required in gallons per minute of any pipe diameter and flushing velocity not shown in Table 5.5, or if you wish to verify any numbers in Table 5.5, use the following procedure.

1. Calculate the cross-sectional area of the pipe in square feet. Use a 10-inch diameter pipe.

$$\text{Area, sq ft} = \frac{(0.785)(\text{Diameter, in})^2}{144 \text{ sq in/sq ft}}$$

$$= \frac{(0.785)(10 \text{ in})^2}{144 \text{ sq in/sq ft}}$$

$$= 0.545 \text{ sq ft}$$

2. Calculate the flow rate in cubic feet per second (CFS). Use a velocity of five feet per second and $Q = AV$.

$$\text{Flow Rate, CFS} = (\text{Area, sq ft})(\text{Velocity, ft/sec})$$

$$= (0.545 \text{ sq ft})(5 \text{ ft/sec})$$

$$= 2.725 \text{ CFS}$$

3. Convert the flow from cubic feet per second to gallons per minute.

$$\text{Flow Rate, GPM} = (\text{Flow, cu ft/sec})(7.48 \text{ gal/cu ft})(60 \text{ sec/min})$$

$$= (2.725 \text{ cu ft/sec})(7.48 \text{ gal/cu ft})(60 \text{ sec/min})$$

$$= 1{,}223 \text{ GPM}$$

NOTE: Table 9.5 shows a flow of 1220 GPM because this is as close as you can read most flow meters, as well as regulate the flow.

C. Disinfection Methods

Next a method of disinfection must be selected. Chlorine gas may be used. A trained operator is required to operate the solution-feed chlorinator in combination with a booster pump. Applying gas directly from a cylinder is dangerous and if proper mixing of chlorine and water is not obtained, a highly corrosive condition could develop.

Another danger is that water could be drawn back into the chlorine cylinder. A mixture of water and liquid chlorine will form a very concentrated hydrochloric acid solution. This acid solution could "eat" a hole in the wall of the cylinder and allow liquid or gaseous chlorine to escape. For these reasons, *NEVER* use water on a chlorine leak. The corrosive action of chlorine and water will *ALWAYS* make a leak worse.

Calcium hypochlorite is available in powder, granular or tablet form at 65 percent available chlorine. Calcium hypochlorite is relatively soluble in water and can be applied by the use of a solution feeder. When using calcium hypochlorite (chlorine) tablets, the tablets will not dissolve readily if the water temperature is below 41°F (5°C), which will reduce the chlorine concentration in the water being disinfected. Temperature control of water is difficult, but you can control contact time. Therefore, if you are disinfecting when the water temperature is low, increase the contact time to achieve effective disinfection.

Calcium hypochlorite requires special storage to avoid contact with organic material. When organic material and calcium hypochlorite come in contact, the resulting chemical reactions can generate enough heat and oxygen to start and support a fire. When calcium hypochlorite is mixed with water, heat is given off. To adequately disperse the heat generated, the dry calcium hypochlorite should be added to the correct volume of water, rather than adding water to the calcium hypochlorite.

Sodium hypochlorite is available in liquid form at five to fifteen percent available chlorine and can be fed by the use of a hypochlorinator. Sodium hypochlorite can lose from two to four percent of its available chlorine content per month at room temperatures. Therefore, manufacturers recommend a maximum storage period of from 60 to 90 days.

See Section 5.4, "Operation of Chlorination Equipment," for procedures on how to operate equipment.

Three common methods of disinfecting mains are summarized in Table 5.6, "Chlorination Methods for Disinfecting Water Mains," and two methods are illustrated in Figures 5.3 and 5.4.

TABLE 5.6 CHLORINATION METHODS FOR DISINFECTING WATER MAINS

Chlorination Method Used	Maximum Chlorine Dose, mg/*L*[b]	Minimum Contact Time, hr	Minimum Chlorine Residual, mg/*L*
Continuous	50	24	25
Slug	500	3	300
Tablet[a]	50	24	25

[a] Tablets must be placed at inside top of pipe when the pipe is being laid. Also, two tablets must be placed at all joints on both sides of the pipe at the half-full location. Place one ounce (28 gm) of HTH powder per inch (25 mm) of pipe diameter in the first length of pipe and again after each 500 feet (150 m) of pipe. This assures that the first water entering the spaces at joints will have a high chlorine residual. Fill the pipe with water at velocities of less than one ft/sec.

[b] *NOTE:* AWWA Standard (601-81 recommends the following doses: Continuous, 25 mg/*L*; Slug, 100 mg/*L*; and Tablet, 25 mg/*L*. Use whatever dose you need that will produce no positive coliform test results.

WARNING

Do not use HTH powder in pipes with solvent welded plastic or screwed joint steel pipe because reaction between the joint compounds and the calcium hypochlorite could cause a fire or an explosion.

1. *NEW MAINS*

All pipes, fittings, valves, and other items which will not be disinfected by the filled line must be precleaned and disinfected. Valve bonnets and other high spots where cleaning may not be effective due to air pockets should be precleaned and chlorinated. Calcium hypochlorite tablets may be crushed and placed in joints and hydrant branches to assist in the total disinfection process.

When applying chlorine by either the continuous or slug method, be sure that the chlorine fed is well mixed with the water used to fill the pipe. Solution feeders can be used to inject chlorine into the water (continuous or slug method) used to disinfect the main. If possible, recycle the flows from the continuous method to minimize the use of chlorine and any problems that might be encountered from disposal of water with a high chlorine residual.

Care must be exercised when disposing of all water with a high chlorine residual (greater than 1 mg/*L*). Possible means of disposal include sanitary sewers, storm sewers or on land. If sanitary sewers are used, there should be adequate dilution and travel time so there will be no chlorine residual when the water reaches the wastewater treatment plant. Be sure to notify the plant operator in advance. If a storm sewer is used, be sure there is no chlorine residual remaining when the water reaches the receiving waters (creek, river, or lake). Chlorine is toxic to fish and other aquatic life. Land disposal may be acceptable if percolation rates are high and there are no nearby wells pumping groundwater.

2. *MAIN REPAIRS*

   a. If repairs are made with the line continuously full of water and under pressure, no disinfection is required.

   b. Where lines are opened:

      (1) Dewater open trench areas using trash pumps,
      (2) Flush and swab all portions of all pipe, fittings, and materials used in repairs, and which will be in contact with the water supply, with a 5 percent hypochlorite solution,
      (3) Flush system, and
      (4) Disinfect the main. Slug disinfection is recommended if practical using 500 mg/*L* dosage and 30-minute minimum contact.

D. Flushing After Disinfection

Flush lines after disinfection under all alternative procedures until residual chlorine is less than 1 mg/*L*. Velocity of flushing is not critical if the preventive and preliminary procedures described above were adequately performed.

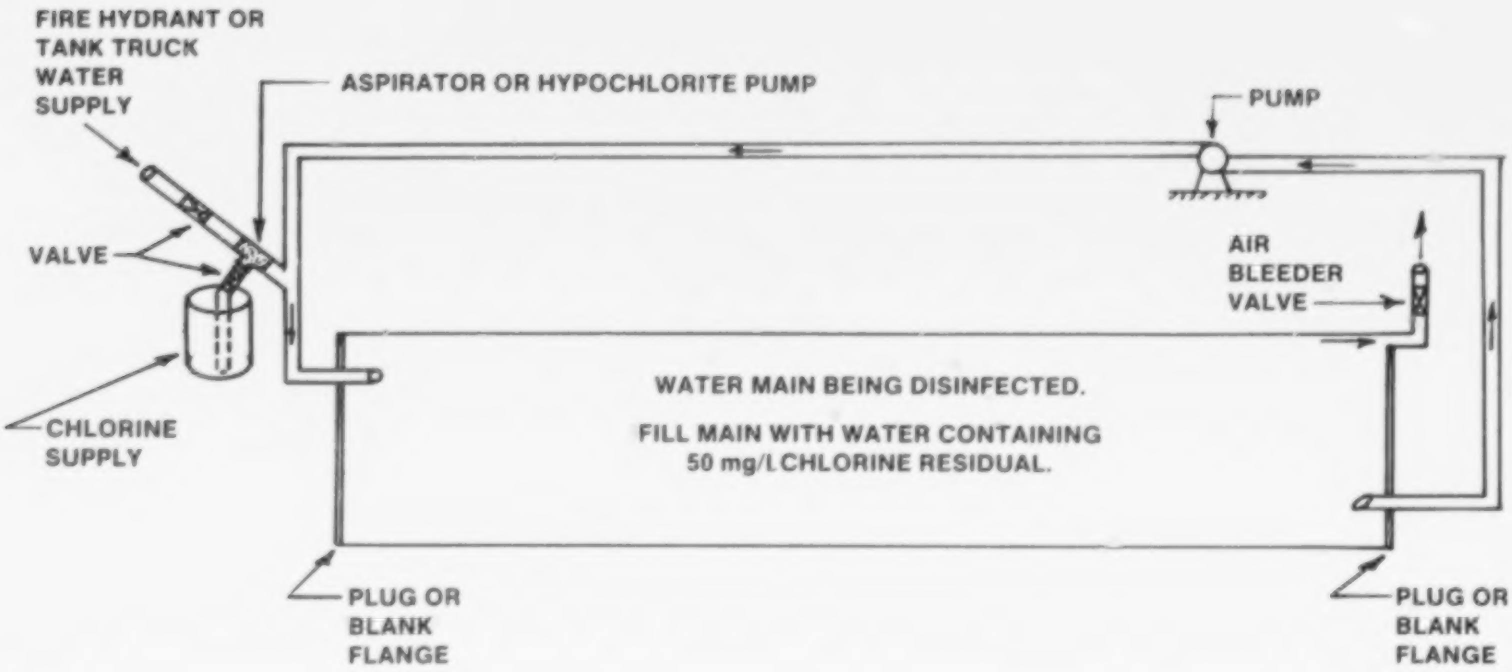
E. Testing After Disinfection

After disinfection and prior to placing line in service, bacteriological tests (24-hour membrane filter) are required as follows:

1. In a chlorinated water system, test at least one sample for each section disinfected.
2. Test at least two samples for each section disinfected if an unchlorinated water system.
3. For long lines, test samples along line. Line in excess of 2500 feet (750 meters) is considered a long line.

If bacteriological tests are unsatisfactory, disinfection must be repeated. Repeat of tablet method, of course, is impossible and an alternative procedure must be used.

A suggested procedure is to flush the main again and then take additional samples. Be sure the sample tap is satisfactory because many unsatisfactory samples from new mains are the result of using poor sample taps such as fire hydrants and blow-off valves.


FIRE HYDRANT OR
TANK TRUCK
WATER
SUPPLY
ASPIRATOR OR HYPOCHLORITE PUMP
PUMP
VALVE
AIR
BLEEDER
VALVE
CHLORINE
SUPPLY
WATER MAIN BEING DISINFECTED.
FILL MAIN WITH WATER CONTAINING
50 mg/L CHLORINE RESIDUAL.
PLUG OR
BLANK
FLANGE
PLUG OR
BLANK
FLANGE

CHLORINE SUPPLY

CAN USE HYPOCHLORITE AND PREMIX SOLUTION PRIER TO INJECTION.

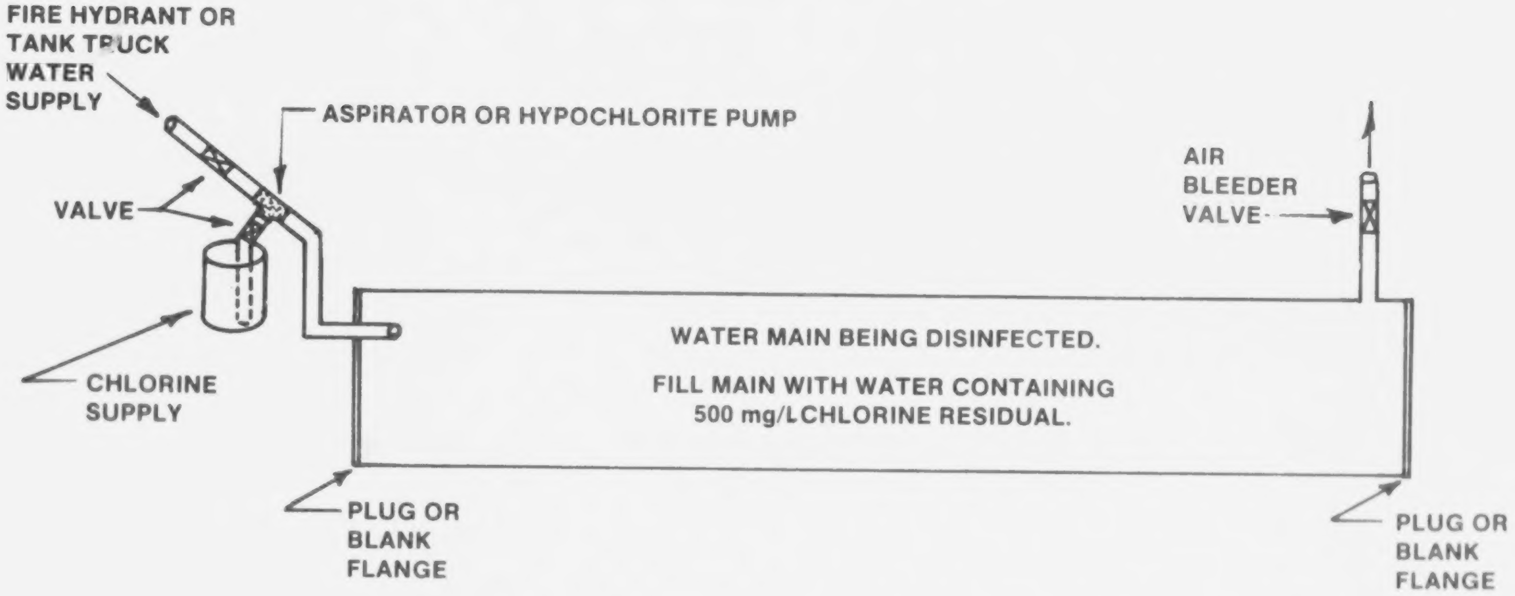
FILLING MAIN

WATER AND CHLORINE SOLUTION SHOULD BE ADDED UNTIL MAIN IS COMPLETELY FULL. ALLOW AIR TO ESCAPE THROUGH AIR BLEEDER VALVE.

EMPTYING MAIN

USE CAUTION WHEN DISPOSING OF DISINFECTING SOLUTION. IF DISCHARGING TO SEWER SYSTEM BE SURE THAT THE PLANT OPERATOR IS NOTIFIED. DISCHARGE WATER TO SEWER VERY SLOWLY OVER A PERIOD OF TIME RATHER THAN IN ONE LARGE SLUG.

Fig. 5.3 Disinfection of a water main by the continuous method


FIRE HYDRANT OR TANK TRUCK WATER SUPPLY
ASPIRATOR OR HYPOCHLORITE PUMP
VALVE
CHLORINE SUPPLY
AIR BLEEDER VALVE
WATER MAIN BEING DISINFECTED.
FILL MAIN WITH WATER CONTAINING 500 mg/L CHLORINE RESIDUAL.
PLUG OR BLANK FLANGE
PLUG OR BLANK FLANGE

CHLORINE SUPPLY

RECOMMEND USING HYPOCHLORITE. TABLETS CAN BE USED, BUT NOT AS EFFECTIVE.

FILLING MAIN

WATER AND CHLORINE SOLUTION SHOULD BE ADDED UNTIL WATER COMES OUT AIR BLEEDER VALVE.

EMPTYING MAIN

DISCHARGE DISINFECTING SOLUTION TO SEWER IF AVAILABLE. NOTIFY PLANT OPERATOR. IF SEWER NOT AVAILABLE, HAUL TO NEAREST WASTEWATER PLANT. DISCHARGE TO SEWER OR AT PLANT VERY SLOWLY AND DILUTE IF NECESSARY SO A SHOCK LOAD WILL NOT REACH PLANT.

Fig. 5.4 Disinfection of a water main by the slug method

If samples are still unsatisfactory, dewater the main as completely as possible. Use air compressors to blow out all remaining water. Refill the empty main with water containing a chlorine residual between 50 and 100 mg/*L*. Allow this water to stand in the main for 48 hours. Flush the main again and resample. Also collect samples from the water entering the main to be sure that this water is not the source of the positive coliform test results.

5.311 Emergency or Maintenance Disinfection

Mains may be disinfected by spraying a high concentration of chlorine on the insides of the mains. This method is often used for disinfecting sections of a water main where a break is repaired or where a crew has cut into an existing main, or in the very short (less than 100 feet or 30 meters) extension of an existing main. This method is frequently used when the main must be quickly returned to service and you can't wait for a 24-hour contact time.

Spray with a solution of one to five percent (10,000 to 50,000 mg/*L*) chlorine at a pressure of 100 psi (690 kPa or 7 kg/sq cm). An ordinary pressure type stainless steel fire extinguisher will do the job. Spray the complete interior of each section of pipe or fitting as it is lowered into the trench. The stainless steel extinguisher will not corrode as rapidly from contact with the chlorine solution if the interior of the tank is lined with a protective coating, such as a chlorinated rubber or an epoxy coating.

5.312 Disinfection Specifications

If water mains are to be disinfected by others as part of a contract, the following should be included in the specifications:

1. Specify AWWA C601-81 as the standard for disinfection procedures to be followed,
2. Specify where flushing may be done, rates of flushing, and location of suitable drainage facilities,
3. Form of chlorine to be used and method of application,
4. The type, number and frequency of samples for bacteriological tests,
5. The method of taking samples, and
6. Who is responsible for testing and use of a certified laboratory.

5.313 Areas of Disinfection Problems

When disinfecting mains, there are certain aspects which are most likely to cause problems. Joints and connections must be thoroughly cleaned before the mains are disinfected. Whenever anyone connects a service line into a main, they must use clean tools and materials. Each service line should be disinfected before being connected to a water main.

Some water supply systems may be lax with their disinfection practices. Personnel working for these systems are sometimes inadequately trained, under-paid and understaffed. They use the excuse that they have neither the time nor the budget to adequately disinfect new mains and existing mains after repairs.

THERE IS NO EXCUSE NOR REASON FOR EVER PLACING A LINE IN SERVICE THAT HAS NOT BEEN ADEQUATELY DISINFECTED AND CONFIRMED BY THE 24-HOUR MEMBRANE FILTER TEST FOR COLIFORMS.

5.314 Sample Problem

FORMULAS

Use the same formulas that are used to disinfect a well.

EXAMPLE 2

A new 6-inch water main 500 feet long needs to be disinfected. An initial chlorine dose of 400 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the three-hour disinfection period. How many gallons of 5 percent sodium hypochlorite solution will be needed?

Known	**Unknown**
Diameter of Pipe, in = 6 in	5% Hypochlorite, gallons
Length of Pipe, ft = 500 ft	
Chlorine Dose, mg/*L* = 400 mg/*L*	
Hypochlorite, % = 5%	

1. Calculate the volume of water in the pipe in gallons.

$$\text{Pipe Volume, gallons} = (0.785)(\text{Diameter, ft})^2(\text{Length, ft})(7.48\ \text{gal/cu ft})$$

$$= \frac{(0.785)(6\ \text{in})^2(500\ \text{ft})(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$= 735\ \text{gallons of water}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.000735\ \text{M Gal})(400\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 2.45\ \text{lbs chlorine}$$

3. Calculate the gallons of 5 percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(2.45\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5\%)}$$

$$= 5.9\ \text{gallons}$$

Six gallons of 5 percent solution sodium hypochlorite should do the job.

TANKS!
YOU'RE WELCOME!

5.32 Tanks

5.320 Procedures

Procedures for disinfecting tanks are similar to those used for mains. Thoroughly clean the tank after construction, maintenance or repairs. Add chlorine to the water used to fill the tank during the disinfection process and mix thoroughly. Maintain a chlorine residual of at least 50 mg/*L* for at least six hours and preferably for 24 hours. When the disinfection procedure is completed, carefully dispose of the disinfection water using the same procedures as for disposal of water used to disinfect mains.

When disinfecting large tanks which hold more than one million gallons, it may not be practical or economical to fill and drain the tank with a disinfecting solution with a high chlorine residual. A solution to this problem is to fill the tank, increase the chlorine residual slightly, collect samples, and run bacteriological tests while keeping the tank full of water (see "SPECIAL NOTE, Section 5.34). If results from the 24-hour membrane filter tests are acceptable, the tank may be placed in service. If necessary, dilute the tank contents as the water flows into the distribution system.

Another approach to disinfecting large tanks is to spray the walls with a jet of water containing a chlorine residual of 200 mg/*L*. Thoroughly spraying the walls with water with a high chlorine residual is an effective means of disinfecting large tanks. Operators doing the spraying should wear a self-contained breathing apparatus because the chlorine fumes from the spray water are very unpleasant and could be hazardous to your health. Be sure to provide plenty of ventilation.

5.321 Sample Problem

FORMULAS

Use the same formulas used to disinfect wells.

EXAMPLE 3

A new service storage reservoir needs to be disinfected before being placed in service. The tank is 8 feet high and 20 feet in diameter. An initial chlorine dose of 100 mg/*L* is expected to maintain a chlorine residual of over 50 mg/*L* during the 24-hour disinfection period. How many gallons of five percent sodium hypochlorite solution will be needed?

Known		Unknown
Diameter of Tank, ft	= 20 ft	5% Hypochlorite, gallons
Height of Tank, ft	= 8 ft	
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Hypochlorite, %	= 5%	

1. Calculate the volume of water in the tank in gallons.

$$\begin{aligned}\text{Tank Volume, gallons} &= (0.785)(\text{Diameter, ft})^2(\text{Heights, ft})(7.48\ \text{gal/cu ft})\\ &= (0.785)(20\ \text{ft})^2(8\ \text{ft})(7.48\ \text{gal/cu ft})\\ &= 18{,}800\ \text{gallons}\end{aligned}$$

2. Determine the pounds of chlorine needed.

$$\begin{aligned}\text{Chlorine, lbs} &= (\text{Vol Water, M Gal})(\text{Chlorine Dose, mg}/L)(8.34\ \text{lbs/gal})\\ &= (0.0188\ \text{M Gal})(100\ \text{mg}/L)(8.34\ \text{lbs/gal})\\ &= 15.68\ \text{lbs chlorine}\end{aligned}$$

3. Calculate the gallons of 5 percent sodium hypochlorite solution needed.

$$\begin{aligned}\text{Sodium Hypochlorite Solution, gallons} &= \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}\\ &= \frac{(15.68\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5\%)}\\ &= 37.6\ \text{gallons}\end{aligned}$$

Thirty-eight gallons of five percent sodium hypochlorite solution should do the job.

5.33 Water Treatment Plants

For additional information on disinfection at water treatment plants, see Chapter 4, "Small Water Treatment Plants," Section 4.5, "Disinfection" and Chapter 7, "Disinfection," in *WATER TREATMENT PLANT OPERATION*, Volume I, in this series of manuals.

5.34 Sampling

**SPECIAL NOTE*

Whenever you collect a sample for a bacteriological test (coliforms), be sure to use a sterile plastic or glass bottle. If the sample contains any chlorine residual sufficient sodium thiosulfate should be added to neutralize all of the chlorine residual. Usually 0.1 m*L* of a 10 percent solution of sodium thiosulfate added to the 120 m*L* (4 oz) bottle before sterilization is sufficient, unless you are disinfecting mains or storage tanks. If the chlorine residual in the sample is greater than 15 mg/*L*, more "thio" is required to neutralize the chlorine.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.3D How can water mains be kept clean during construction or repair?

5.3E What areas in a water main require extra effort for successful disinfection?

5.3F List three forms of chlorine used for disinfection.

5.3G What precautions should be taken when disposing of water with a high chlorine residual?

5.3H Before a water main is disinfected, what flushing velocity should be used and for how long?

End of Lesson 1 of 2 Lessons
on
DISINFECTION

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. DISINFECTION

(Lesson 1 of 2 Lessons)

Write the answers to these questions in your notebook before continuing.

1. Why is drinking water disinfected?
2. If a water is disinfected, will it be safe to drink?
3. What is the chlorine demand of a water?
4. How would you determine the chlorine dose for water?
5. Why should a chlorine residual be maintained in a water distribution system?
6. Why would you consider recycling water used to disinfect a water main when using the continuous chlorination method?
7. How would you dispose of the water used to disinfect a water main when using the slug chlorination method?

Chapter 5. DISINFECTION

(Lesson 2 of 2 Lessons)

5.4 OPERATION OF CHLORINATION EQUIPMENT

5.40 Description of Various Units

5.400 Field Equipment

1. *HYPOCHLORINATORS*

Hypochlorinators used on small water systems are very simple and relatively easy to install. Typical installations are shown in Figures 5.5 and 5.6. Hypochlorinator systems usually consists of a chemical solution tank for the hypochlorite, diaphragm-type pump (Figure 5.7), power supply, water pump, pressure switch and water storage tank.

There are two methods of feeding the hypochlorite solution into the water being disinfected. The hypochlorite solution may be pumped directly into the water (Figure 5.8). In the other method, the hypochlorite solution is pumped through an *EDUCATOR*[21] or injector which draws in additional water for dilution of the hypochlorite solution (Figure 5.9).

2. *CHLORINATORS*

Chlorinators or small systems are normally vacuum feed systems (Figures 5.10, 5.11 and 5.12). The chlorine is usually injected directly into the water pipe supply and there may not be contact chambers or mixing units. The location of the injection point is important. The injection should never be on the intake side of the pump as it will cause corrosion problems. There should be a check valve and a meter to monitor the chlorine dose.

On most well applications a chlorine booster pump is needed to overcome the higher water pump discharge pressures. The low volume-high pressure booster pump shown in figure 5.10 must have extremely small clearance between the impeller and the casing. If the well produces sand in the water, this pump will wear rapidly and become unreliable. In this situation, the chlorine solution should be introduced down the well through a polyethylene tube.

The polyethylene tube (½ inch or 12 mm) must be installed in the well so as to discharge a few inches below the suction screen. The chlorinator should operate *ONLY* when the pump is running. The chlorine solution flowing through the polyethylene tube is extremely corrosive. If the tube does not discharge into flowing water, the effect of the solution impinging on metal surface can be disastrous. Wells have been destroyed by corrosion from chlorine.

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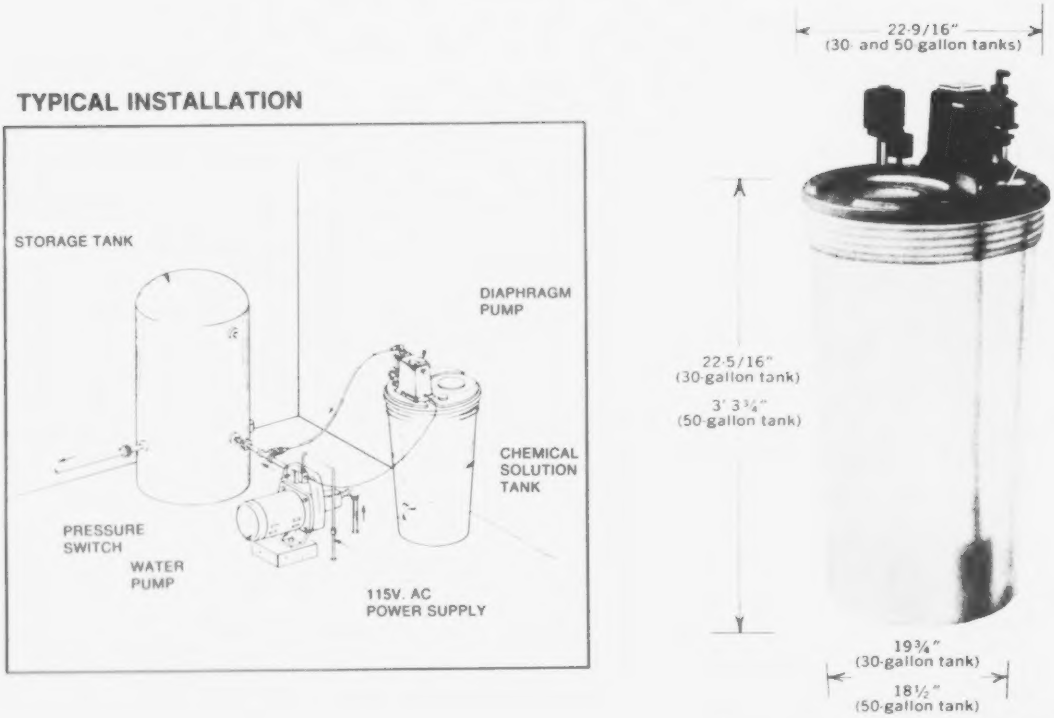
[21] *Eductor (e-DUCK-tor). A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction such as a Venturi.*



Pump-tank system for chemical mixing and metering. Cover supports pump, impeller-type mixer, and liquid-level switch.

Fig 5.5 Typical hypochlorinator installation

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

5.401 Chlorine Containers

1. *HYPOCHLORINATORS*

Plastic containers are sufficient (Figures 5.5 and 5.6). Size depends on usage. Plastic containers should be large enough to hold a two or three day's supply of hypochlorite solution. The solution should be prepared every two or three days. If a greater solution is mixed, the solution may loose its strength and thus effect the chlorine feed rate. Normally a week's supply of hypochlorite should be in storage and available for preparing hypochlorite solutions. Store the hypochlorite in a cool, dark place. Sodium hypochlorite can lose from two to four percent of its available chlorine content per month at room temperatures. Therefore, manufacturers recommend a maximum shelf life of 60 to 90 days.

2. *GAS CHLORINATORS*

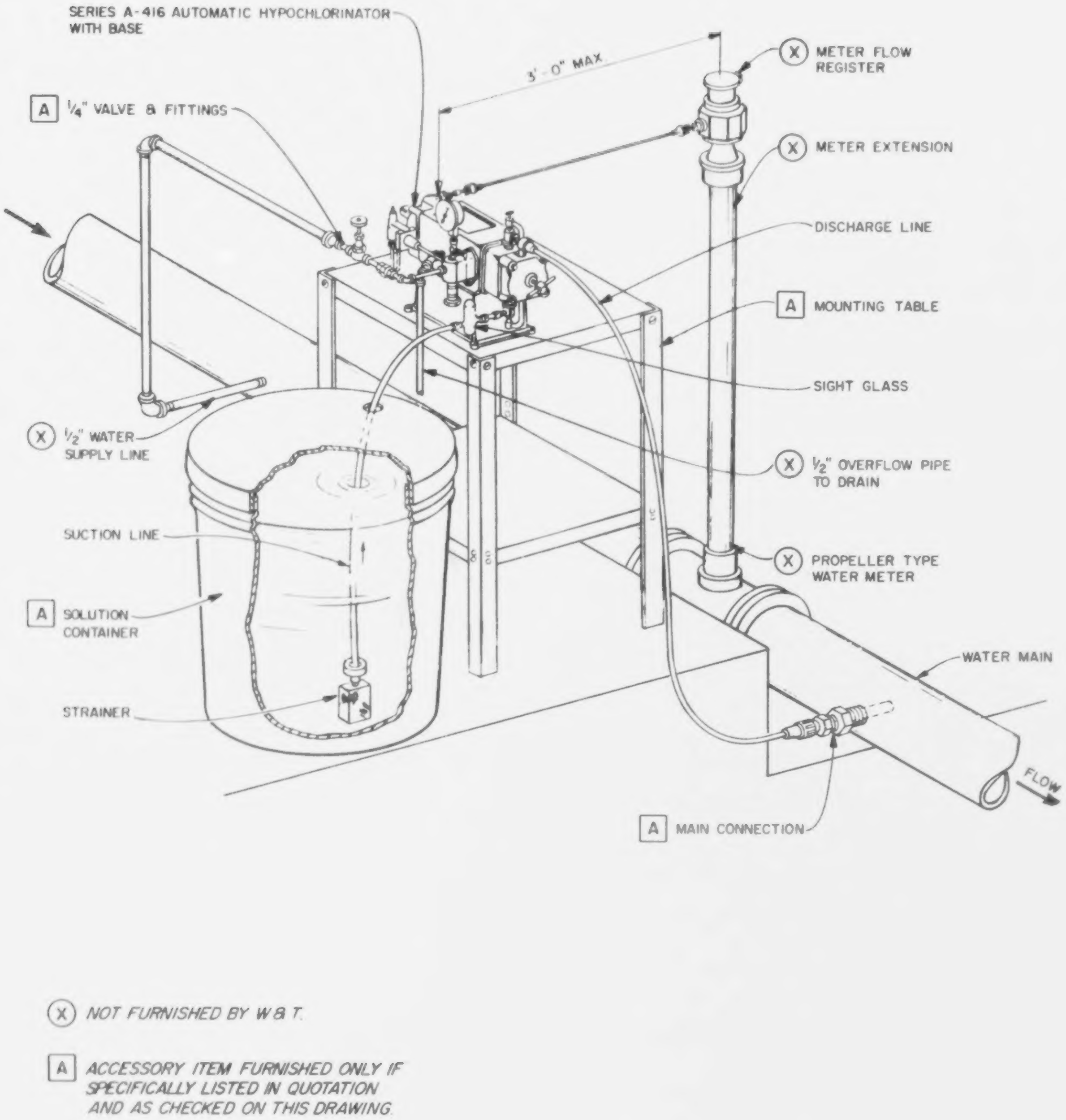
Chlorine is delivered for use by chlorinators in 100 and 150-pound (45 to 68 kg) cylinders (Figures 5.13 and 5.14), one-ton (900 kg) tanks or chlorine tank cars in sizes from 16 to 90 tons (14,500 to 81,800 kg). The 100 and 150-pound (45 to 68 kg) cylinders will be discussed in this section.

These cylinders are usually made of seamless carbon steel. A fusible pump is placed in the vale below the vale seat (Figure 5.15). This plug is a safety device. The fusible metal softens or melts at 158 to 165 degrees F (70 to 74°C) to prevent buildup of excessive pressures and the possibility of rupture due to fire or high surrounding temperatures.

The maximum rate of chlorine removal from a 150-pound (18 kg) cylinder is 40 pounds (18 kg) of chlorine per day. If the rate of removal is greater, "freezing" can occur and less chlorine will be delivered.

WARNING

When frost appears on valves and flex connectors, the chlorine gas may condense to liquid (reliquify). The liquid chlorine may plug the chlorine supply lines (sometimes this is referred to as chlorine ice or frozen chlorine). If you disconnect the chlorine supply line to unplug it, *BE VERY CAREFUL*. The liquid chlorine in the line could reevaporate, expand as a gas, build up pressure in the line, and cause liquid chlorine to come shooting out the open end of a disconnected chlorine supply line.


SERIES A-416 AUTOMATIC HYPOCHLORINATOR WITH BASE
3'-0" MAX
(X) METER FLOW REGISTER
A 1/4" VALVE & FITTINGS
(X) METER EXTENSION
DISCHARGE LINE
A MOUNTING TABLE
SIGHT GLASS
(X) 1/2" WATER SUPPLY LINE
(X) 1/2" OVERFLOW PIPE TO DRAIN
SUCTION LINE
(X) PROPELLER TYPE WATER METER
A SOLUTION CONTAINER
WATER MAIN
STRAINER
FLOW
A MAIN CONNECTION
(X) NOT FURNISHED BY W & T.
A ACCESSORY ITEM FURNISHED ONLY IF SPECIFICALLY LISTED IN QUOTATION AND AS CHECKED ON THIS DRAWING.

NOTE: Hypochlorinator paced by a propeller-type water meter.

Fig. 5.6 Typical hypochlorinator installation
(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

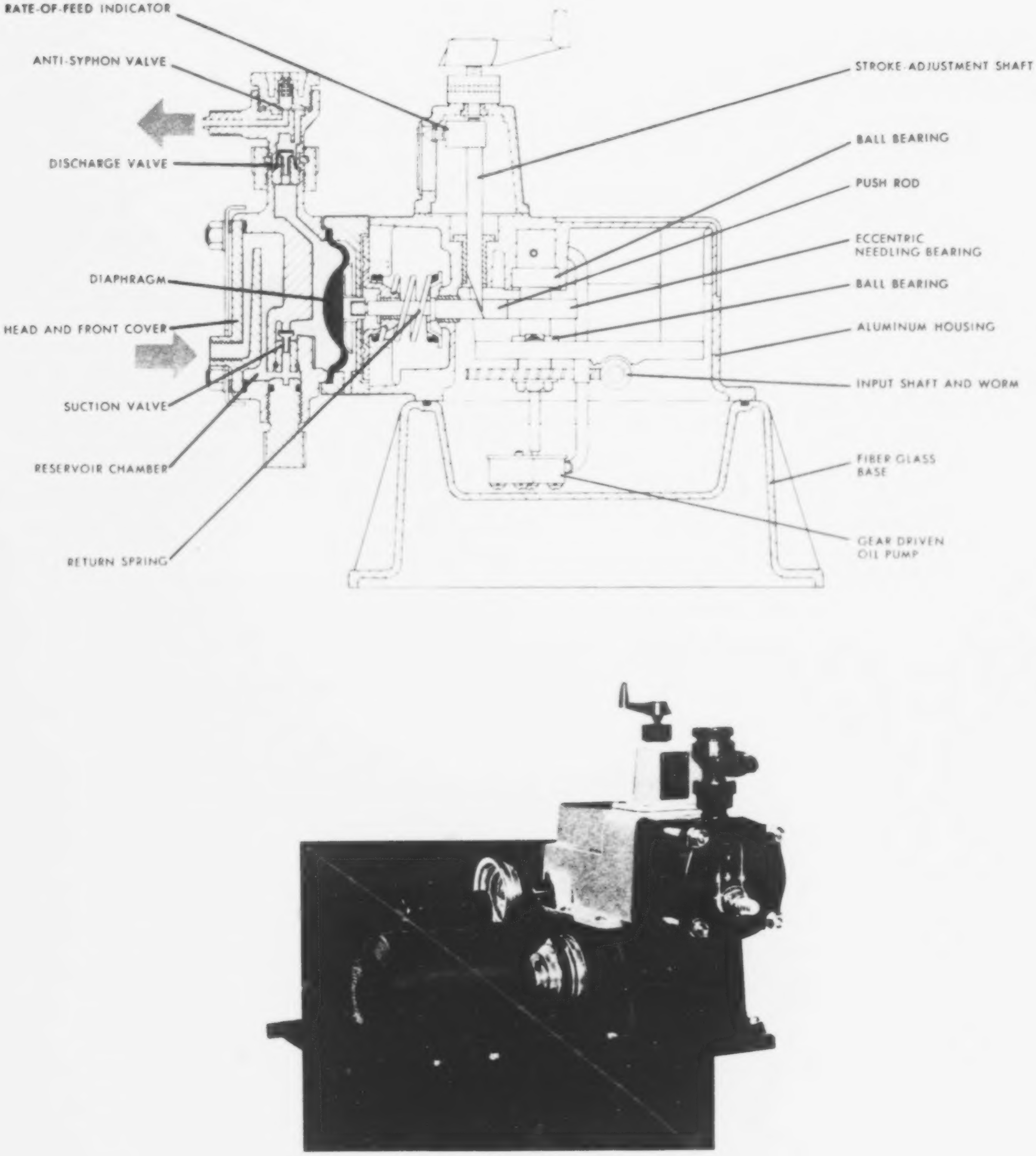

RATE-OF-FEED INDICATOR
ANTI-SYPHON VALVE
DISCHARGE VALVE
DIAPHRAGM
HEAD AND FRONT COVER
SUCTION VALVE
RESERVOIR CHAMBER
RETURN SPRING
STROKE-ADJUSTMENT SHAFT
BALL BEARING
PUSH ROD
ECCENTRIC NEEDLING BEARING
BALL BEARING
ALUMINUM HOUSING
INPUT SHAFT AND WORM
FIBER GLASS BASE
GEAR DRIVEN OIL PUMP

Fig. 5.7 Diaphragm-type pump

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

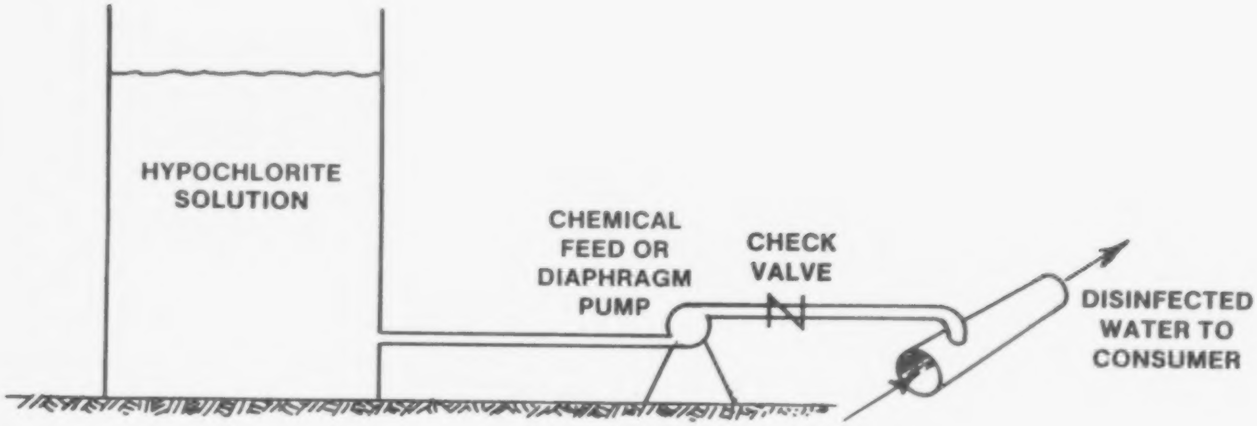
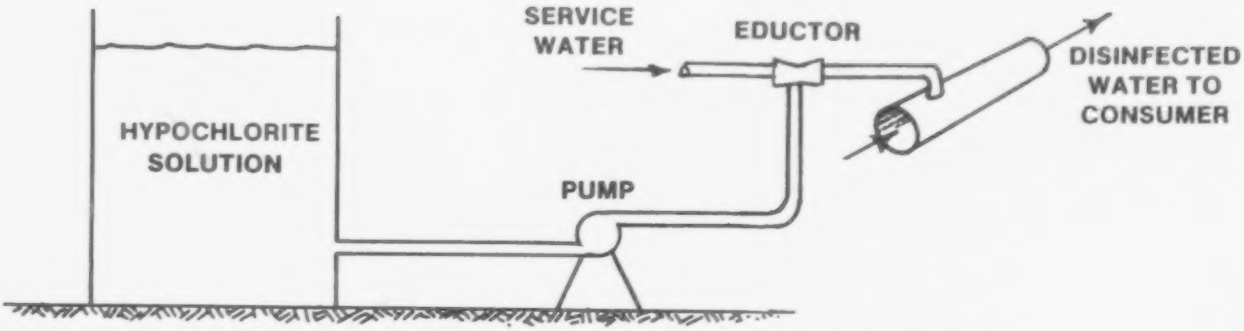

HYPOCHLORITE SOLUTION
CHEMICAL FEED OR DIAPHRAGM PUMP
CHECK VALVE
DISINFECTED WATER TO CONSUMER

Fig. 5.8 Hypochlorinator direct pumping system


SERVICE WATER
EDUCTOR
DISINFECTED WATER TO CONSUMER
HYPOCHLORITE SOLUTION
PUMP

NOTE: Pump is chemical feed or diaphragm pump

Fig. 5.9 Hypochlorinator injector feed system

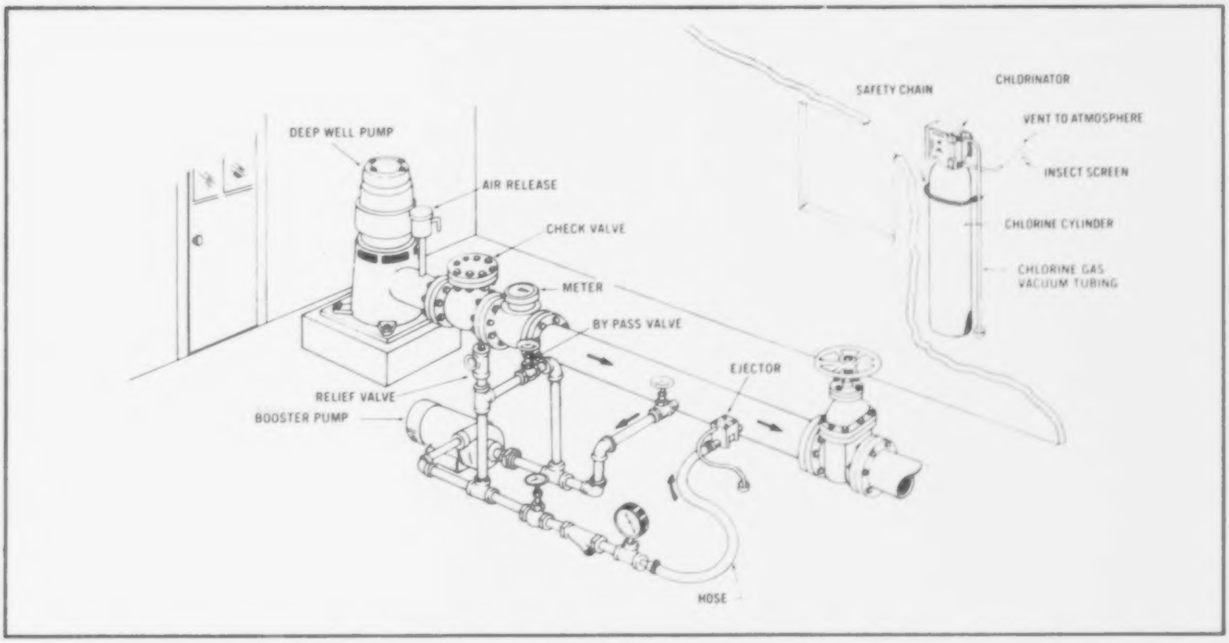

SAFETY CHAIN
CHLORINATOR
VENT TO ATMOSPHERE
DEEP WELL PUMP
INSECT SCREEN
AIR RELEASE
CHLORINE CYLINDER
CHECK VALVE
CHLORINE GAS VACUUM TUBING
METER
BY PASS VALVE
EJECTOR
RELIEF VALVE
BOOSTER PUMP
HOSE

Fig. 5.10 Typical deep well chlorination system

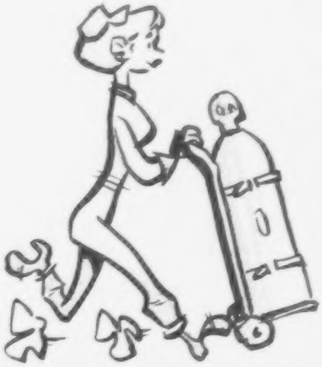
(Permission of Capital Controls Company, Colmar, Pa.)

5.41 Chlorine Handling

Cylinders containing 100 to 150 pounds (45 to 68 kg) of chlorine are convenient for very small plants with capacities less than 0.5 MGD (1890 cu m/day or 1.89 *ML*/day).[22]

The following are procedures for safely handling chlorine cylinders.

1. Move cylinders with a properly balanced hand truck with clamp supports that fasten at least two-thirds of the way up the cylinder (Figure 5.16).



2. 100- and 150-pound (45 to 68 kg) cylinders can be rolled in a vertical position. Avoid lifting these cylinders except with approved equipment. Never lift with chains, rope slings, or magnetic hoists.
3. Always replace the protective cap when moving a cylinder.
4. Keep cylinders away from direct heat (steam pipes or radiators).
5. Store cylinders in an upright position. All empty chlorine cylinders (depressurized) must be tagged as empty.
6. Remove the outlet cap from the cylinder and inspect the threads on the outlet. Cylinders having outlet threads which are corroded, worn, cross-threaded, broken, or missing should be rejected and returned to the supplier.
7. The specifications and regulations of the U.S. Interstate Commerce Commission require that chlorine cylinders be tested at 800 psi (5516 kPa or 56.24 kg/sq cm) every five years. The date of testing is stamped on the dome of the cylinder. Cylinders which have not been tested within that period of time should be rejected and returned to the supplier.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.4A List the two major types of chlorine feeders.

5.4B Why are chlorine booster pumps needed on most well applications?

5.4C What is the maximum rate of chlorine removal from a 150-pound cylinder?

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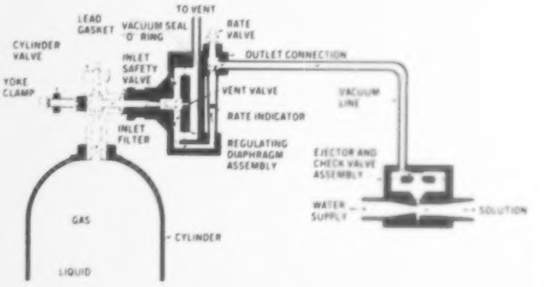
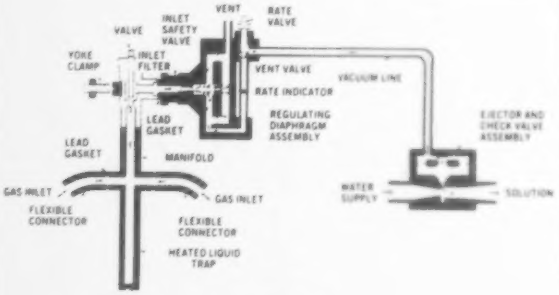
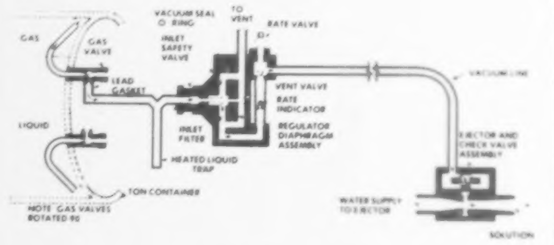
[22] *ML/day. Megaliters or million liters per day.*


TO VENT
LEAD GASKET
VACUUM SEAL 'O' RING
RATE VALVE
CYLINDER VALVE
OUTLET CONNECTION
INLET SAFETY VALVE
YOKE CLAMP
VENT VALVE
VACUUM LINE
RATE INDICATOR
INLET FILTER
REGULATING DIAPHRAGM ASSEMBLY
EJECTOR AND CHECK VALVE ASSEMBLY
WATER SUPPLY
SOLUTION
GAS
CYLINDER
LIQUID

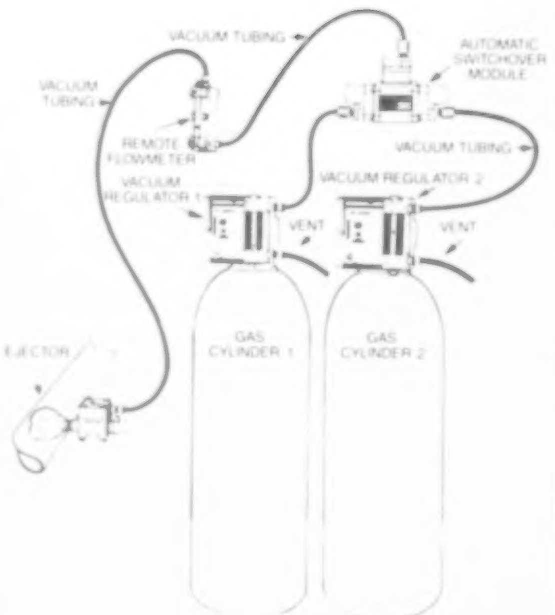
Flow Diagram
Direct Cylinder Mounted Unit


VENT
RATE VALVE
INLET SAFETY VALVE
VALVE
YOKE CLAMP
INLET FILTER
VENT VALVE
VACUUM LINE
RATE INDICATOR
LEAD GASKET
REGULATING DIAPHRAGM ASSEMBLY
EJECTOR AND CHECK VALVE ASSEMBLY
LEAD GASKET
MANIFOLD
GAS INLET
GAS INLET
WATER SUPPLY
SOLUTION
FLEXIBLE CONNECTOR
FLEXIBLE CONNECTOR
HEATED LIQUID TRAP

Flow Diagram
Manifold Mounted Unit


VACUUM SEAL O RING
TO VENT
RATE VALVE
GAS
GAS VALVE
INLET SAFETY VALVE
VACUUM LINE
LEAD GASKET
VENT VALVE
RATE INDICATOR
LIQUID
REGULATOR DIAPHRAGM ASSEMBLY
INLET FILTER
EJECTOR AND CHECK VALVE ASSEMBLY
HEATED LIQUID TRAP
TON CONTAINER
NOTE GAS VALVES ROTATED 90
WATER SUPPLY TO EJECTOR
SOLUTION

Flow Diagram
Ton Container Mounted Unit


VACUUM TUBING
AUTOMATIC SWITCHOVER MODULE
VACUUM TUBING
REMOTE FLOWMETER
VACUUM TUBING
VACUUM REGULATOR 1
VACUUM REGULATOR 2
VENT
VENT
EJECTOR
GAS CYLINDER 1
GAS CYLINDER 2

Automatic Switchover Operation
100 PPD (2000 g/hr) Cylinder Mounted System Shown

Fig. 5.11 Typical chlorinator flow diagrams
(Permission of Capital Controls Company, Colmar, Pa.)

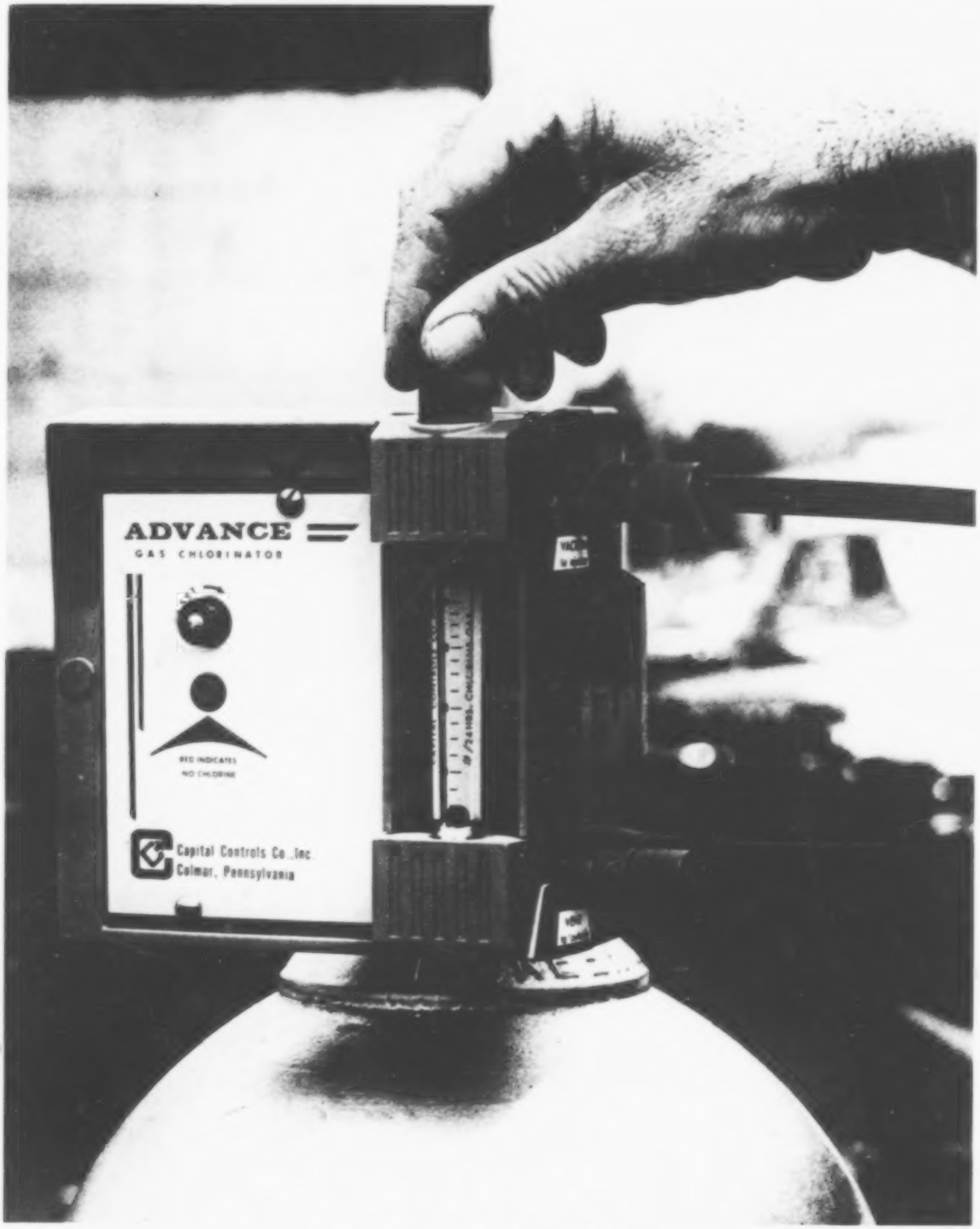
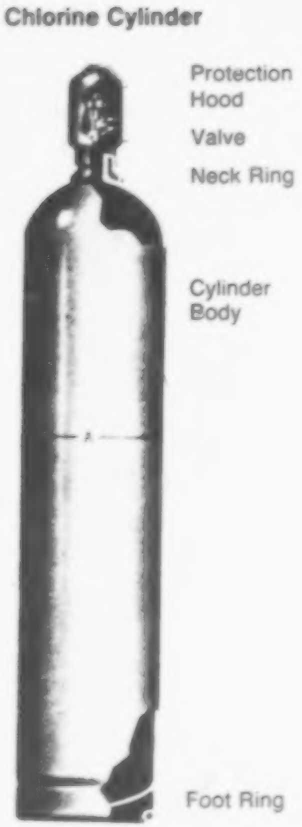

ADVANCE
GAS CHLORINATOR
RED INDICATES
NO CHLORINE
Capital Controls Co., Inc.
Colmar, Pennsylvania
#/24 HRS. CHLORINE GAS

Fig. 5.12 Chlorinator with rotameter showing feed rate in #/24 hrs chlorine gas

(Permission of Capital Controls Company, Colmar, Pa.)

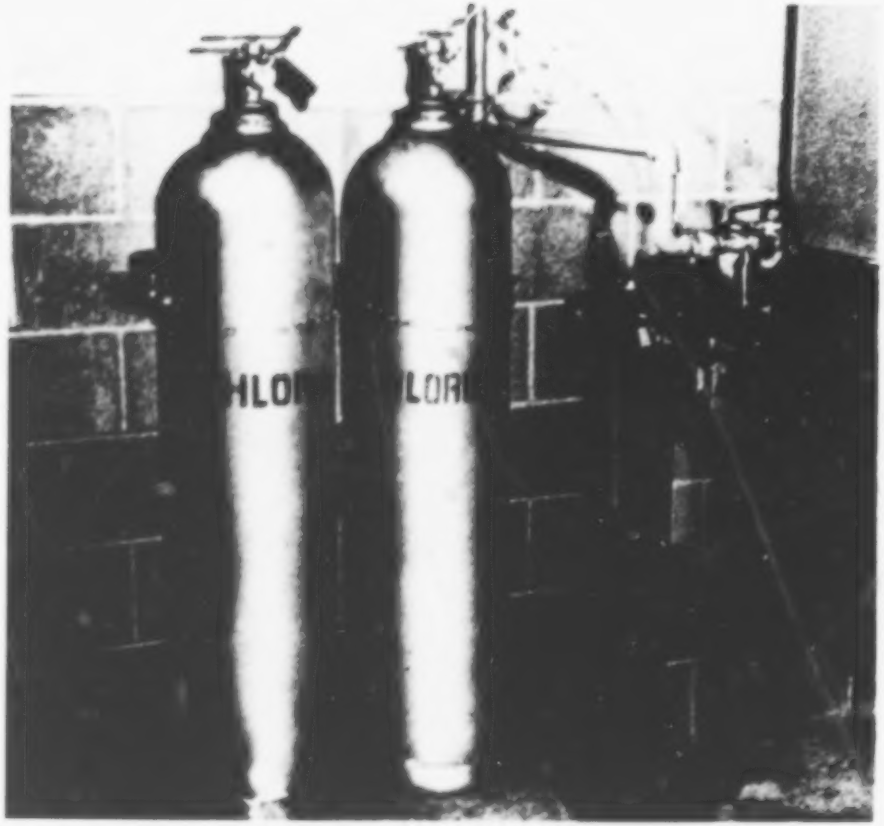

Chlorine Cylinder
Protection Hood
Valve
Neck Ring
Cylinder Body
A
Foot Ring

Net Cylinder Contents	Approx. Tare, Lbs.*	Dimensions, Inches	
		A	B
100 Lbs.	73	8 1/4	54 1/2
150 Lbs.	92	10 1/4	54 1/2

*Stamped tare weight on cylinder shoulder does not include valve protection hood.

Fig. 5.13 *Chlorine cylinder*

(Courtesy of PPG Industries)

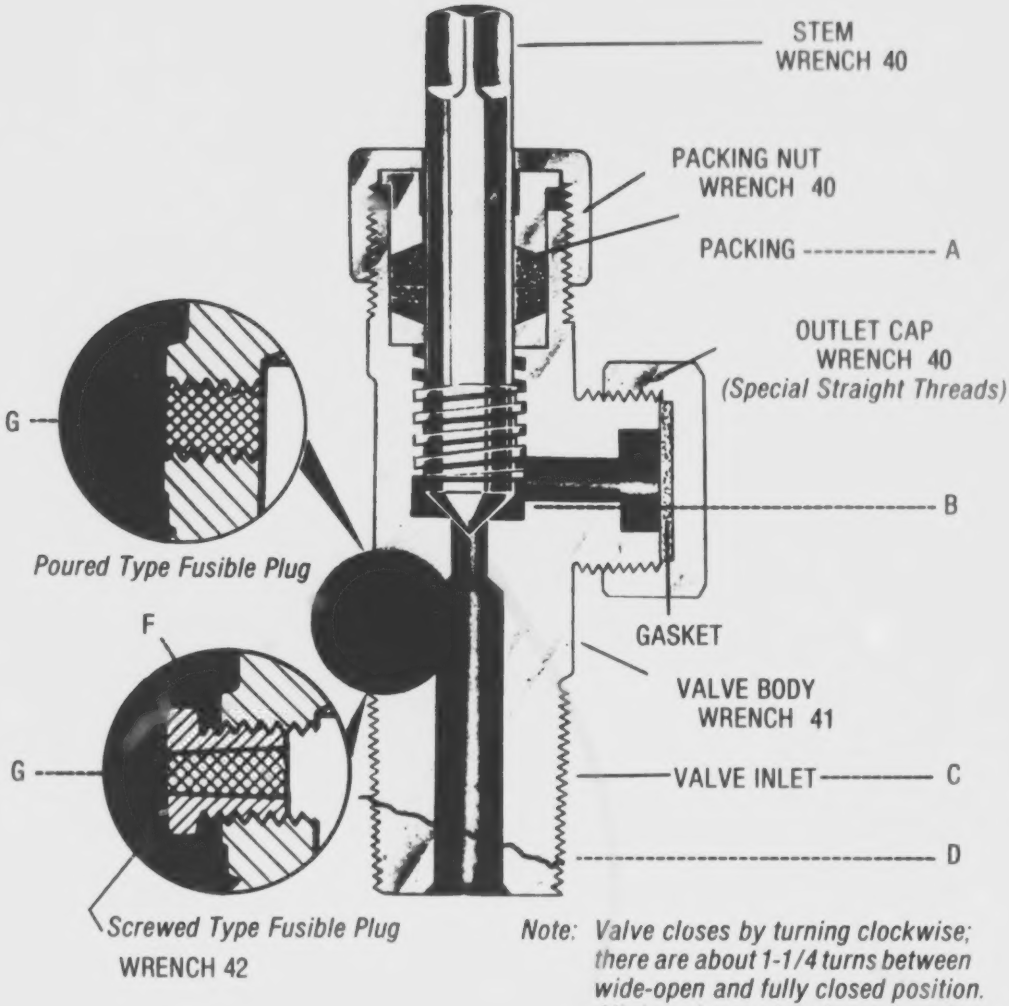

CHLORI
CHLORI

NOTES:

1. Scale for weighing chlorine cylinders and chlorine.
2. Flexible tubing (pig tail).
3. Cylinders chained to wall.

Fig. 5.14 *Typical chlorine cylinder station for water treatment*

(Courtesy of PPG Industries)


STEM
WRENCH 40
PACKING NUT
WRENCH 40
PACKING ------------ A
OUTLET CAP
WRENCH 40
(Special Straight Threads)
G
B
Poured Type Fusible Plug
F
GASKET
VALVE BODY
WRENCH 41
G
VALVE INLET---------- C
D
Screwed Type Fusible Plug
WRENCH 42

Note: Valve closes by turning clockwise; there are about 1-1/4 turns between wide-open and fully closed position. All threads are right-hand threads.

TYPICAL VALVE LEAKS OCCUR THROUGH . . .

A - VALVE PACKING GLAND
B - VALVE SEAT
C - VALVE INLET THREADS
D - BROKEN OFF VALVE
E - VALVE BLOWN OUT
F - FUSIBLE PLUG THREADS
G - FUSIBLE METAL OF PLUG
H - VALVE STEM BLOWN OUT

Fig. 5.15 Standard chlorine cylinder valve
(Permission of Chlorine Specialties, Inc.)

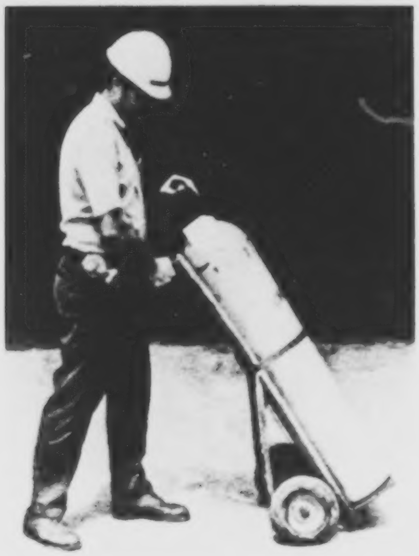


Fig.5.16 Hand truck for chlorine cylinder
(Courtesy of PPG Industries)

5.42 Performance of Chlorination Units

5.420 Hypochlorinators

1. *HYPOCHLORINATOR STARTUP*
   a. Solution. Chemical solutions have to be made up. Most agencies buy commercial or industrial hypochlorite at around 12 to 15 percent chlorine. This solution is usually diluted down to a two percent solution. If using commercially prepared solutions, dosage rates will have to be calculated.
   b. Electrical. Lock out the circuit while making an inspection of an electrical circuit. Normally no adjustments are needed. Look for frayed wires. Turn the power back on. Leave the solution switch off.
   c. Turn the chemical pump on. Make any necessary adjustments while the pump is running. Never adjust the pump while it is off because damage to the pump will occur.
   d. Make sure the solution is being fed into system.
   e. Check the chlorine residual in the system. Residual should be at least 0.2 mg/*L* throughout the distribution system. Adjust the chemical feed as required.
2. *HYPOCHLORINATOR SHUTDOWN*
   a. Short Duration
      (1) Turn the water supply pump off. You do not want to pump any unchlorinated water and possibly contaminate the rest of the system.
      (2) Turn the hypochlorinator off.
      (3) When making any repairs, lock out the circuit or pull the plug from an electric socket.
   b. Long Duration
      (1) Obtain another hypochlorinator as a replacement.
3. *NORMAL OPERATION OF HYPOCHLORINATOR*

Normal operation of the hypochlorination process requires routine observation and preventive maintenance.

DAILY

a. Inspect the building to make sure only authorized personnel have been there.

BOSS: ONLY AUTHORIZED PERSONNEL HAS BEEN HERE!

b. Read and record the level of the solution tank at the same time every day.

c. Read the meters and record the amount of water pumped.

d. Check the chlorine residual (0.2 mg/*L*) in the system and adjust the chlorine feed rate as necessary. Try to maintain a chlorine residual of 0.2 mg/*L* at the most remote point in the distribution system. The suggested free chlorine residual for treated water or well water is 0.5 mg/*L* at the point of chlorine application provided the 0.2 mg/*L* is maintained throughout the distribution system.

e. Check the chemical feed pump operation. Most hypochlorinators have a dial with a range from 0 to 10 which indicates the chlorine feed rate. Initially set the pointer on the dial to approximately 6 or 7 on the dial and use a two percent hypochlorite solution. The pump should be operated in the upper ranges of the dial. This will require the frequency of the strokes or pulses from the pump to be frequent enough so that the chlorine will be fed continuously to the water being treated. Adjust feed rate after testing chlorine residual levels.

WEEKLY

a. Clean the building.

b. Replace the chemicals and wash the chemical storage tank. Try to have a 15 to 30-day supply of chlorine in storage for future needs. When preparing hypochlorite solutions, prepare only enough for a two or three-day supply.

MONTHLY

a. Check the operation of the check valve.

b. Perform any required preventive maintenance.

c. Cleaning

Commercial sodium hypochlorite solutions (such as chlorox) contain an excess of caustic (sodium hydroxide or NaOH). When this solution is diluted with water containing calcium and also carbonate alkalinity, the resulting solution becomes supersaturated with calcium carbonate. This calcium carbonate tends to form a coating on the poppet valves in the solution feeder. The coated valves will not seal properly and the feeder will fail to feed properly.

Use the following procedure to remove the carbonate scale:

(1) Fill a one quart (one liter) Mason jar half full of tap water.
(2) Place one fluid ounce (20 m*L*) of 30 to 37 percent hydrochloric acid (swimming pool acid) in the jar. *ALWAYS ADD ACID TO WATER, NEVER THE REVERSE.*
(3) Fill the jar with tap water.
(4) Place the suction hose of the hypochlorinator in the jar and pump the entire contents of the jar through the system.
(5) Return the suction hose to the hypochlorite solution tank and resume normal operation.

You can prevent the formation of the calcium carbonate coatings by obtaining the dilution water from an ordinary home water softener.

NORMAL OPERATION CHECKLIST

a. Check chemical usage. Record solution level and the water pump meter reading or number of hours of pump operation. Calculate the amount of chemical solution used and compare with the desired feed rate. See EXAMPLE 4.

b. Determine if every piece of equipment is operating.

c. Inspect the lubrication of the equipment.

d. Check the building for any possible problems.

e. Clean up the area.

FORMULAS

To determine the actual chlorine dose of water being treated by either a chlorinator or a hypochlorinator, we need to know the gallons of water treated and the pounds of chlorine used to disinfect the water.

1. Calculate the pounds of water disinfected.

Water, lbs = (Water Pumped, gallons)(8.34 lbs/gal)

2. To calculate the volume of hypochlorite used from a container, we need to know the dimensions of the container.

$$\text{Volume, gallons} = \frac{(0.785)(\text{Diameter, in})^2(\text{Depth, ft})(7.48 \text{ gal/cu ft})}{144 \text{ sq in/sq ft}}$$

3. To calculate the pounds of chlorine used to disinfect water, we need to know the gallons of hypochlorite used and the percent available chlorine in the hypochlorite solution.

$$\text{Chlorine, lbs} = (\text{Hypochlorite, gal})(8.34 \text{ lbs/gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)$$

4. To determine the actual chlorine dose in milligrams per liter, we divide the pounds of chlorine used by the millions of pounds of water treated. Pounds of chlorine per million pounds of water is the same as parts per million or milligrams per liter.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}}$$

EXAMPLE 4

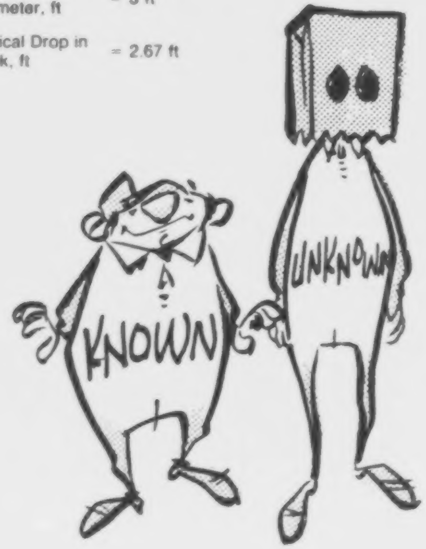
Water pumped from a well is disinfected by a hypochlorinator. A chlorine dosage of 1.2 mg/*L* is necessary to maintain an adequate chlorine residual throughout the system. During a one-week time period, the water meter indicated that 2,289,000 gallons of water were pumped. A two-percent sodium hypochlorite solution is stored in a three-foot diameter plastic tank. During this one-week period, the level of hypochlorite in the tank dropped 2 feet, 8 inches (2.67 feet). Does the chlorine feed rate appear to be too high, too low or about right?

Known

Desired Chlorine Dose, mg/L = 1.2 mg/L
Water Pumped, gal = 2,289,000 gal
Hypochlorite, % = 2%
Chemical Tank Diameter, ft = 3 ft
Chemical Drop in Tank, ft = 2.67 ft

Unknown

1. Actual Chlorine Dose, mg/L
2. Is Actual Dose OK?



1. Calculate the pounds of water disinfected.

$$\begin{aligned} \text{Water, lbs} &= (\text{Water Pumped, gallons})(8.34\ \text{lbs/gal}) \\ &= (2{,}289{,}000\ \text{gal})(8.34\ \text{lbs/gal}) \\ &= 19{,}090{,}000\ \text{lbs} \\ &= 19.09\ \text{Million lbs} \end{aligned}$$

2. Calculate the volume of 2 percent sodium hypochlorite used in gallons.

$$\begin{aligned} \text{Hypochlorite, gallons} &= (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft}) \\ &= (0.785)(3\ \text{ft})^2(2.67\ \text{ft})(7.48\ \text{gal/cu ft}) \\ &= 141.1\ \text{gallons} \end{aligned}$$

3. Determine the pounds of chlorine used to disinfect the water.

$$\begin{aligned} \text{Chlorine lbs} &= (\text{Hypochlorite, gal})(8.34\ \text{lbs/gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right) \\ &= (141.1\ \text{gal})(8.34\ \text{lbs/gal})\left(\frac{2\%}{100\%}\right) \\ &= 23.5\ \text{lbs chlorine} \end{aligned}$$

4. Calculate the chlorine dosage in mg/L.

$$\begin{aligned} \text{Chlorine Dose, mg/}L &= \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}} \\ &= \frac{23.5\ \text{lbs chlorine}}{19.09\ \text{Million lbs water}} \\ &= 1.23\ \text{mg/}L \end{aligned}$$

Since actual chlorine dose (1.23 mg/L) was slightly greater than the desired dose of 1.2 mg/L, the chlorine feed rate appears OK.

4. *ABNORMAL OPERATION OF HYPOCHLORINATOR*

a. Inform your Supervisor of the problem.

b. If the hypochlorinator malfunctions, it should be repaired immediately. See the shutdown operation (Step 2 in this section).

c. Solution tank level.

(1) If Too Low — Check the adjustment of the pump.
Check the hour meter of the water pump.

(2) If Too High — Check the chemical pump.
Check the hour meter of the water pump.

d. Determine if the chemical pump is not operating.

TROUBLESHOOTING GUIDELINES

ELECTRICAL CONNECTION

(1) Check the electrical connection.
(2) Check the circuit breaker.
(3) Check for stoppages in the flow lines.

CORRECTIVE MEASURES

(1) Shut off the water pump so that no contaminated water is pumped into the system.
(2) Check for a blockage in the solution tank.
(3) Check the operation of the check valve.
(4) Check the electrical circuits.
(5) Replace the chemical feed pump with another pump while repairing the defective unit.

e. The solution is not being pumped into the water line.

TROUBLESHOOTING GUIDELINES

(1) Check the solution level.
(2) Check for blockages in the solution line.

5. *MAINTENANCE OF HYPOCHLORINATORS*

Hypochlorinators on small systems are normally small, sealed systems that cannot be repaired so replacement of the entire unit is the only solution. Maintenance requirements are normally minor such as changing the oil and lubricating the moving parts. Review the manufacturer's specifications for maintenance requirements.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.4D What is the basis for adjusting the chemical feed of a hypochlorinator?

5.4E When should the level of the hypochlorite solution tank be read?

5.4F What is the basis for determining the strength of the hypochlorite solution in the solution tank?

5.4G What maintenance is usually required of hypochlorinators?

5.421 Chlorinators

1. *SAFETY EQUIPMENT REQUIRED AND AVAILABLE OUTSIDE THE CHLORINATOR ROOM*

   a. Protective clothing

      (1) Gloves
      (2) Rubber suit

   b. Self-contained pressure-demand air supply system (Figure 5.17)

2. *STARTUP OF CHLORINATORS*

Work in pairs. Never work alone when hooking up a chlorine system.

   a. Inspect the chlorine container for leaks.

   b. Inspect the chlorination equipment.

   c. Use new gaskets for hookup of the chlorinator to supply containers. Gaskets should be stored in a refrigerator or other cool, dark place so they won't deteriorate before you want to use them.

   d. Prior to the hookup, inspect for moisture and foreign substances in the lines.

   e. Have an ammonia bottle readily available to detect any leaks in the system. Dip a rag on the end of a stick in the ammonia[23] bottle and place the rag near the location of suspected leaks. A white cloud will reveal the location of a chlorine leak.

   f. Have safety equipment available which may be used in case of a leak.

   g. Hook up the chlorinator to the chlorine container with the chlorine valve turned off. Use the gas side (not liquid side) if using a ton tank.

   h. Open the chlorine valve slightly and check for leaks. Remember — don't leave the valve in this position for a long time because it will plug up. Commercial chlorine usually contains small amounts of chlorinated organic compounds which are not volatile. Trace amounts of these compounds can be carried over in the chlorine vapor. A slightly opened valve, with the resulting change in velocity, is an ideal place for these materials to collect, build up and cause the valve to plug up. Open the valve to prevent plugging.

   i. Adjust the chlorinator to the proper setting. The desired chlorine residual should be maintained throughout the distribution system. Coliform test results should be negative when the chlorination system is operating properly.

3. *CHLORINATOR SHUTDOWN*

Work in pairs. A plan should be used where both people are not exposed to the chlorine at the same time.

   a. Have safety equipment available in the event of a chlorine leak.

   b. Shut off the chlorine valve from the supply source.

   c. Allow sufficient time for the chlorine to purge out of the line.

   d. Turn the chlorinator off.

   e. Leave the discharge line open. If chlorine is trapped between two valves, the chlorine gas can expand when heated by sunlight and develop high pressures in the line. Leave the discharge line open to prevent this hazard from developing.

4. *NORMAL OPERATION OF CHLORINATORS*

Normal operation of a chlorinator requires routine observation and preventive maintenance.

DAILY

   a. Inspect the building to make sure that only authorized personnel have been there.

   b. Read the chlorinator rotameter.

   c. Record the reading, time, date and initial the entries.

   d. Read the meters and record the number of gallons of water pumped.

   e. Check the chlorine residual. If the residual is below 0.2 mg/*L* in the distribution system, increase the feed rate by adjusting the rotameter. If the residual is too high, lower the feed rate by adjusting the rotameter.

   f. Calculate the chlorine usage. Refer to EXAMPLES 5 and 6.

WEEKLY

   a. Clean the equipment and the building.

   b. Perform preventive maintenance on the equipment.

Chlorine usage should be calculated so that replacement supply containers can be ordered and constant chlorination can be maintained. Refer to EXAMPLE 7. Try to have a 15 to 30-day supply of chlorine in storage.

NORMAL OPERATION CHECKLIST

   a. Chemical usage in pounds.

   b. Meter readings for water usage in gallons.

   c. Equipment log.

   d. Lubrication inspection log.

   e. Building inspection.

5. *ABNORMAL OPERATION*

   a. Inform supervisor of the problem.

   b. If the chlorinator malfunctions, repair the unit immediately.

---

[23] *Use a concentrated ammonia solution containing 28 to 30 percent ammonia as NH_3 (this is the same as 58 percent ammonium hydroxide, NH_4OH, or commercial 26° Baume).*

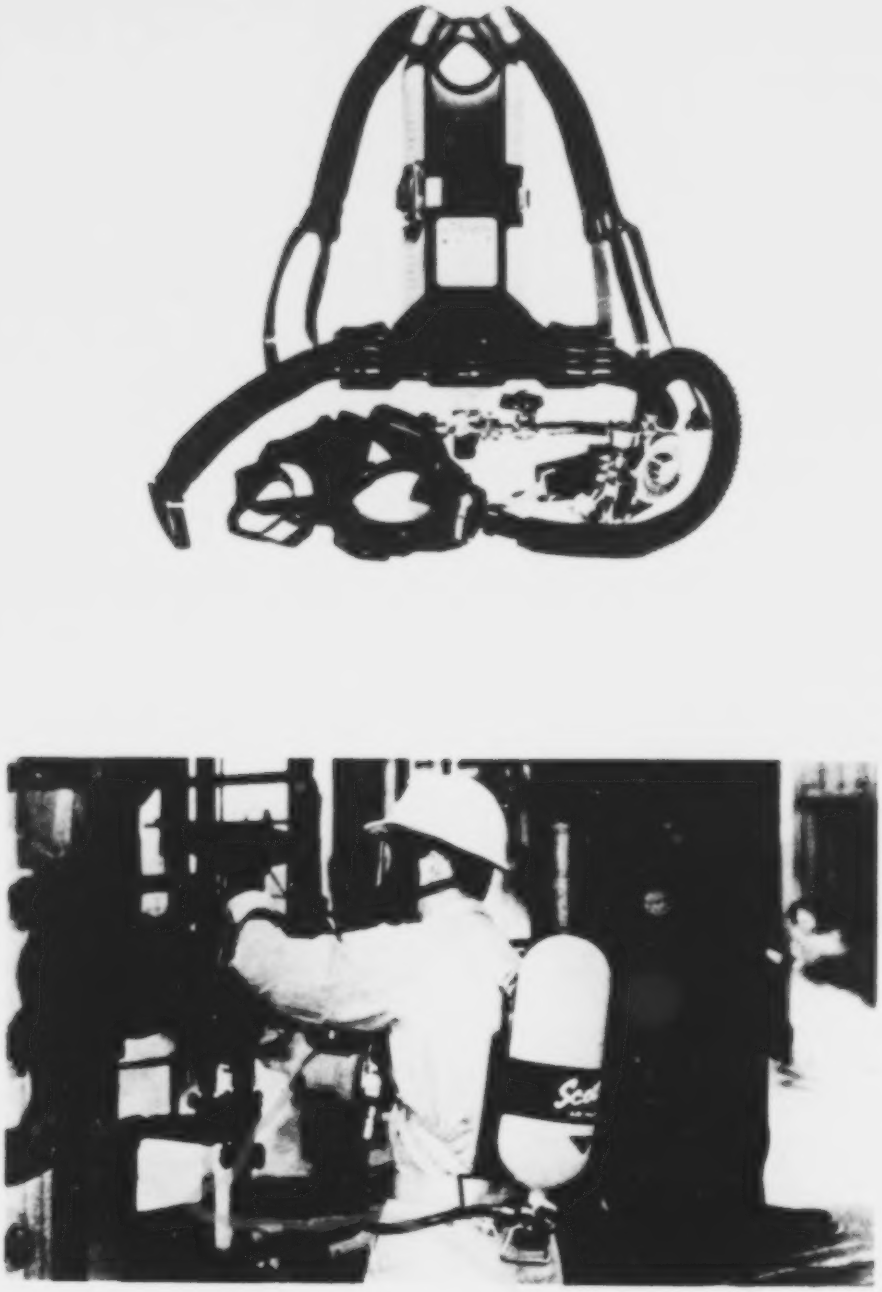


Fig. 5.17 Self-contained breathing apparatus

(Courtesy of PPG Industries)

c. If repairs cannot be completed quickly, shut off the water supply so that unchlorinated or contaminated water will not be delivered to the consumers.

ABNORMAL OPERATION, TROUBLESHOOTING

a. Chlorine not feeding. Troubleshooting

   (1) Check the chlorine supply system.
   (2) Check the electrical system.
   (3) Check for blockages in line.

6. *MAINTENANCE*

Most chlorinators are simple units and are more easily replaced than repaired on-line. Remove and repair in shop or have repaired by others who do not have to operate the system.

FORMULAS

To determine the setting on a chemical feeder in pounds per day, multiply the flow in MGD times the dose in mg/*L* times 8.34 lbs/gal.

$$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

To calculate the number of chlorine cylinders used per month, determine the pounds of chlorine used per month and divide by the pounds of chlorine per cylinder.

$$\text{Cylinders Used, number/month} = \frac{\text{Chlorine Used, lbs/mo}}{\text{Chlorine Cylinders, lbs/cylinder}}$$

EXAMPLE 5

A deep-well turbine pump delivers approximately 200 GPM against typical operating heads. If the desired chlorine dose is 2 mg/*L*, what should be the setting on the rotameter for the chlorinator (lbs chlorine per 24 hours)?

Known	Unknown
Pump Flow, GPM = 200 GPM	Rotameter Setting, lbs chlorine/24 hours
Chlorine Dose, mg/*L* = 2 mg/*L*	

1. Convert pump flow to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{(200\text{ GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

$$= 0.288\text{ MGD}$$

2. Calculate the rotameter setting in pounds of chlorine per 24 hours.

$$\begin{aligned}\text{Rotameter Setting, lbs/day} &= (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})\\ &= (0.288\text{ Mil Gal/day})(2\text{ mg}/L)(8.34\text{ lbs/gal})\\ &= 4.8\text{ lbs/day}\\ &= 4.8\text{ lbs/24 hours}\end{aligned}$$

EXAMPLE 6

Using the results from EXAMPLE 5 (a chlorinator setting of 4.8 lbs/day), how many pounds of chlorine would be used during one week if the pump hour meter showed 100 hours of pump operation? If the chlorine cylinder contained 78 pounds of chlorine at the start of the week, how many pounds of chlorine should be remaining at the end of the week?

Known	Unknown
Chlorinator Setting, lbs/day = 4.8 lbs/day	1. Chlorine Used, lbs/week
Time, hrs/week = 100 hr/week	2. Chlorine Remaining, lbs
Chlorine Cylinder, lbs = 78 lbs	

1. Calculate the chlorine used in pounds per week.

$$\begin{aligned}\text{Chlorine Used, lbs/week} &= (\text{Chlorinator Setting, lbs/day})(\text{Time, hrs/week})\\ &= (4.8\text{ lbs/day})\left(\frac{100\text{ hrs/wk}}{24\text{ hrs/day}}\right)\\ &= 20\text{ lbs chlorine/week}\end{aligned}$$

2. Determine the amount of chlorine that should be remaining in the cylinder at the end of the week.

$$\begin{aligned}\text{Chlorine Remaining, lbs} &= \text{Chlorine at Start, lbs} - \text{Chlorine Used, lbs}\\ &= 78\text{ lbs} - 20\text{ lbs}\\ &= 58\text{ lbs chlorine remaining at end of week}\end{aligned}$$

EXAMPLE 7

Given the pumping rate and chlorination system in EXAMPLES 5 and 6. If 20 pounds of chlorine are used during an average week, how many 150-pound chlorine cylinders will be used per month (assume 30 days per month).

Known	Unknown
Chlorine Use, lbs/week = 20 lbs/week	1. Amount of Chlorine Used per Month, lbs
	2. Number of 150-lb Cylinders Used per Month

1. Calculate the amount of chlorine used in pounds of chlorine per month.

$$\begin{aligned}\text{Chlorine Used, lbs/month} &= (\text{Chlorine Use, lbs/week})(\text{Number Weeks/mo})\\ &= (20\text{ lbs/week})\left(\frac{(1\text{ week})(30\text{ days})}{(7\text{ days})(1\text{ month})}\right)\\ &= 85.7\text{ lbs/month}\end{aligned}$$

2. Determine the number of 150-pound chlorine cylinders used per month.

$$\begin{aligned}\text{Cylinders Used, number/month} &= \frac{\text{Chlorine Used, lbs/mo}}{\text{Chlorine Cylinders, lbs/cylinder}}\\ &= \frac{85.7\text{ lbs/mo}}{150\text{ lbs/cylinder}}\\ &= 0.57\text{ cylinders/month}\end{aligned}$$

This installation requires less than one 150-pound chlorine cylinder per month.

5.43 Laboratory Tests

1. Chlorine residual in system

   a. Daily chlorine residual tests using the *DPD*[24] *METHOD*[25] should be taken at various locations in the system. A remote tap is ideal for one sampling location. Take the test sample from a tap as close to the main as possible. Allow the water to run at least 5 minutes before sampling to assure a representative sample from the main.

---

[24] *DPD. A method for measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N, N-diethyl-p-phenylene-diamine.*

[25] *See Section 5.5, "Measurement of Chlorine Residual," for details on how to perform the DPD test for measuring chlorine residual.*

b. Chlorine residual test kits are available for small systems.

2. Bacteriological Analysis (Coliform Tests)

Samples should be taken routinely in accordance with health department requirements. Take samples according to approved procedures.[26] Be sure to use a sterile plastic or glass bottle. If the sample contains any chlorine residual, sufficient sodium thiosulfate should be added to neutralize all of the chlorine residual. Usually 0.1 milliliter of 10 percent sodium thiosulfate in a 120 mL (4 oz) bottle is sufficient for distribution systems. The "thio" should be added to the sample bottle before sterilization.

5.44 Troubleshooting

TABLE 5.7 DISINFECTION TROUBLESHOOTING GUIDE

Operating Symptoms	Probable Cause	Remedy
1. Increase in coliform level	Low chlorine residual	Raise chlorine dose
2. Drop in chlorine level	a. Increase in chlorine demand b. Drop in chlorine feed rate	Raise chlorine dose and find out why chlorine demand increased or chlorine feed rate dropped

5.45 Chlorination System Failure

IF YOUR CHLORINATION SYSTEM FAILS, DO NOT ALLOW UNCHLORINATED WATER TO ENTER THE DISTRIBUTION SYSTEM. Never allow unchlorinated water to be delivered to your consumers. If your chlorination system fails and cannot be repaired within a reasonable time period, notify your supervisor and officials of the health department. To prevent this problem from occurring, your plant should have backup or standby chlorination facilities.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 278.

5.4H What personal safety equipment should be available before attempting to locate and repair a chlorine gas leak?

5.4I How is ammonia used to detect a chlorine leak?

5.4J What would you do if you could not repair a broken chlorinator quickly?

5.4K What two water quality tests are most commonly run on samples of water from a water supply system?

5.5 MEASUREMENT OF CHLORINE RESIDUAL

5.50 Methods of Measuring Chlorine Residual

AMPEROMETRIC TITRATION[27] provides for the most convenient and most repeatable chlorine residual results. However, amperometric titration equipment is more expensive than equipment for other methods. DPD tests can be used and are less expensive than other methods, but this method requires the operator to match the color of a sample with the colors on a comparator. See Chapter 7, "Laboratory Procedures," for detailed information on these tests.

Residual chlorine measurements of treated water should be taken at least three times per day on small systems and once every two hours on large systems. Residuals are measured to insure that the treated water is being adequately disinfected. A free chlorine residual of at least 0.5 mg/L in the treated water at point of application is usually recommended.

5.51 Amperometric Titration for Free Residual Chlorine

1. Place a 200 mL sample of water in the titrator.
2. Start the agitator.
3. Add 1 mL of pH 7 buffer.
4. Titrate with 0.00564 *N* phenylarsene oxide solution.
5. End point is reached when further additions (drops) will not cause a deflection on the microammeter.
6. mL of phenylarsene oxide used in titration is equal to mg/L of free chlorine residual.

5.52 DPD Colormetric Method for Free Residual Chlorine (Figures 5.18 and 5.19)

This procedure is for the use of prepared powder pillows.

1. Collect a 100 mL sample.
2. Add color reagent.
3. Match color sample with a color on the comparator to obtain the chlorine residual in mg/L.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 279.

5.5A What two methods are commonly used to measure chlorine residual in treated water?

5.5B How often should treated water residual chlorine measurements be made?

5.6 CHLORINE SAFETY PROGRAM

Every good safety program begins with cooperation between the employee and the employer. The employee must take an active part in the overall program. The employee must be responsible and should take all necessary steps to prevent accidents. This begins with the attitude that as good an effort as possible must be made by everyone. Safety is everyone's problem. The employer also must take an active part by supporting safety programs. There must be funding to purchase equipment and to enforce safety regulations required by OSHA and state industrial safety programs. The following items should be included in all safety programs.

1. Establishment of a formal safety program.
2. Written rules.
3. Periodic hands-on training using safety equipment.
   a. Leak-detection equipment
   b. Self-contained breathing apparatus (Figure 5.17).
   c. Atmospheric monitoring devices

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[26] *See Chapter 7, "Laboratory Procedures," for proper procedures for collecting and analyzing samples for chlorine residuals and coliform tests.*

[27] *Amperometric Titration (am-PURR-o-MET-rick). A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction.*

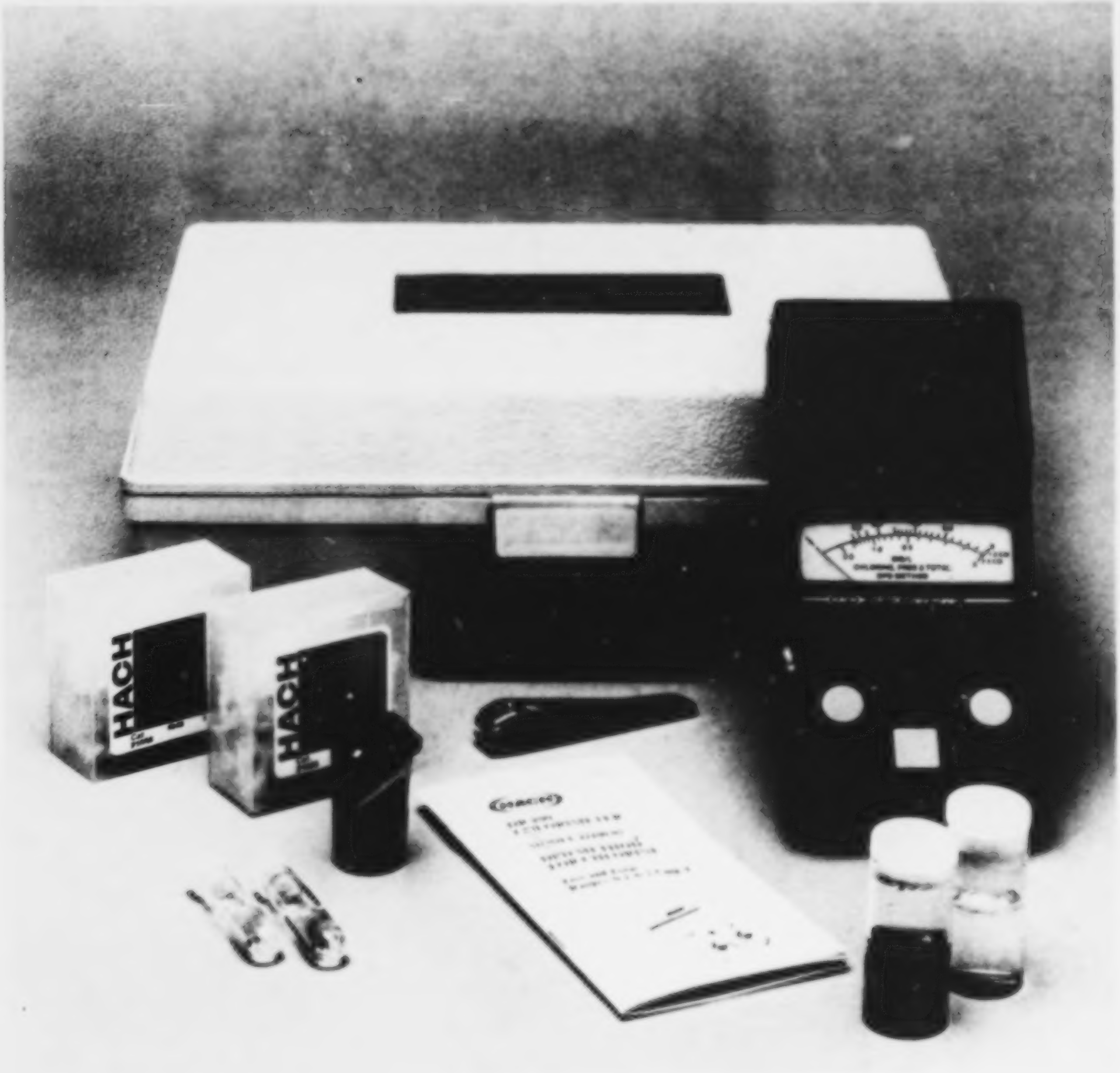

Fig 5.18 Direct reading colorimeter for free chlorine residuals

(Permission of the Hach Company)

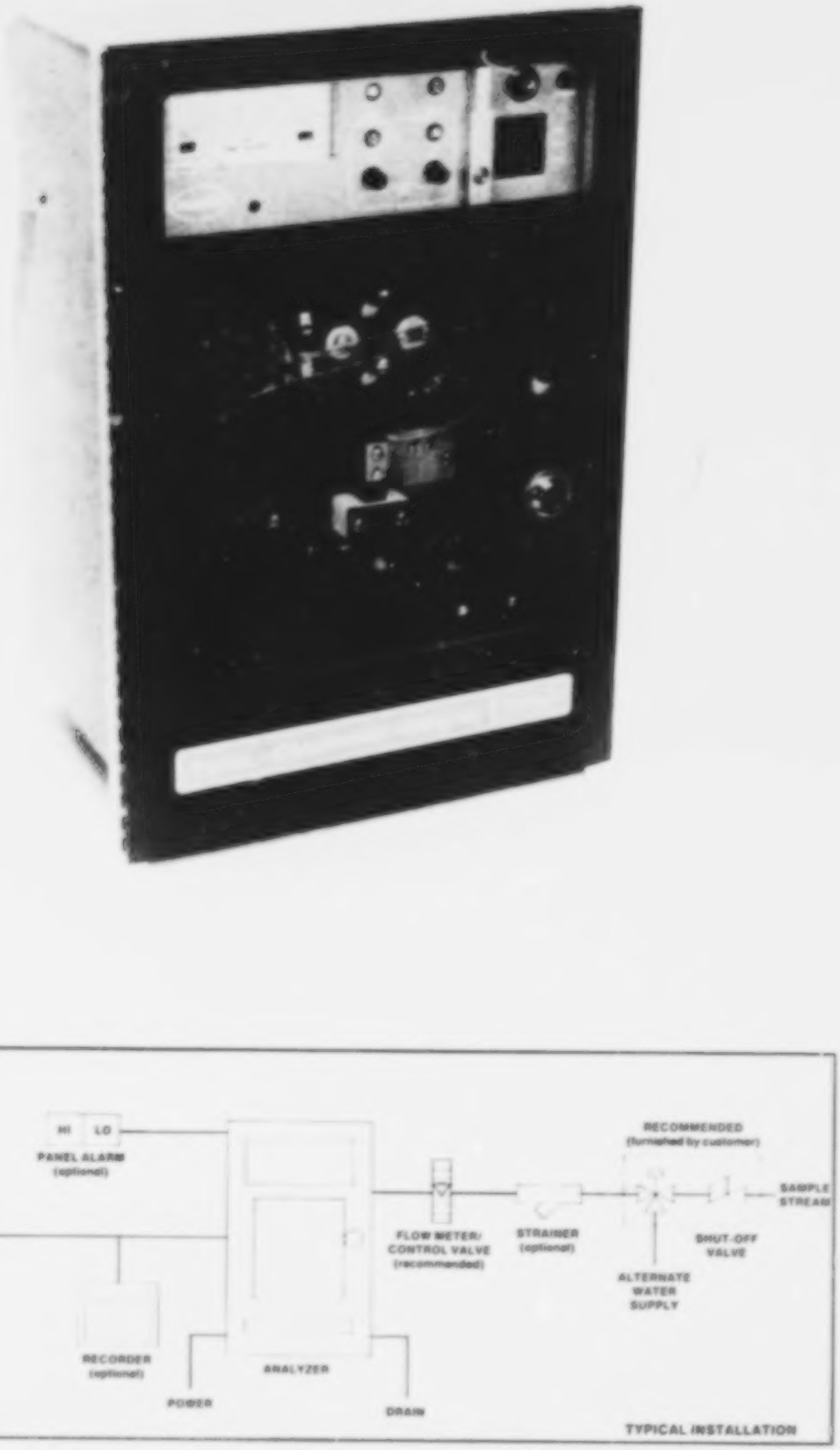
HI
LO
PANEL ALARM
(optional)
RECOMMENDED
(furnished by customer)
SAMPLE
STREAM
FLOW METER/
CONTROL VALVE
(recommended)
STRAINER
(optional)
SHUT-OFF
VALVE
ALTERNATE
WATER
SUPPLY
CONTROLLER
(optional)
RECORDER
(optional)
ANALYZER
POWER
DRAIN
TYPICAL INSTALLATION

Fig 5.19 Continuous on-line free chlorine residual analyzer

(Permission of the Hach Company)

4. Establishment of emergency procedures for chlorine leaks and first aid.
5. Establishment of a maintenance and calibration program for safety devices and equipment.
6. Provide police and fire departments with tours of facilities to locate hazardous areas and provide chlorine safety information.

All persons handling chlorine should be thoroughly aware of its hazardous properties. Personnel should know the location and use of the various pieces of protective equipment and be instructed in safety procedures. In addition, an emergency procedure should be established and each individual should be instructed how to follow the procedures. An emergency checklist also should be developed and available. For additional information on this topic, see the Chlorine Institute's *CHLORINE MANUAL*, 4th Edition.[28] Also see Chapter 6, "Safety."

5.60 Chlorine Hazards

Chlorine is a gas, heavier than air, extremely toxic and corrosive in moist atmospheres. Dry chlorine gas can be safely handled in steel containers and piping, but with moisture must be handled in corrosion-resisting materials such as silver, glass, teflon, and certain other plastics. Chlorine gas at container pressure should never be piped in silver, glass, teflon, or any other material that cannot handle the pressure. Even in dry atmospheres chlorine combines with the moisture in the mucous membranes of the nose and throat, and with the fluids in the eyes and lungs; a very small percentage in the air can be very irritating and can cause severe coughing. Heavy exposure can be fatal (see Table 5.8).

WARNING

WHEN ENTERING A ROOM THAT MAY CONTAIN CHLORINE GAS, OPEN THE DOOR SLIGHTLY AND CHECK FOR THE SMELL OF CHLORINE. **NEVER** GO INTO A ROOM CONTAINING CHLORINE GAS WITH HARMFUL CONCENTRATIONS IN THE AIR WITHOUT A SELF-CONTAINED AIR SUPPLY, PROTECTIVE CLOTHING AND HELP STANDING BY. HELP MAY BE OBTAINED FROM YOUR CHLORINE SUPPLIER AND YOUR LOCAL FIRE DEPARTMENT.

Most people can usually detect concentrations of chlorine gas above 0.3 ppm and you should not be exposed to concentrations greater than 1 ppm. However, chlorine gas can deaden your sense of smell and cause a false sense of security. **NEVER** rely on your sense of smell to protect you from chlorine because **YOUR** sense of smell might not be able to detect harmful levels of chlorine.

5.61 Why Chlorine Must Be Handled With Care

You must always remember that chlorine is a hazardous chemical and must be handled with respect. Concentrations of chlorine gas in excess of 1000 ppm may be fatal after a few breaths.

Because the characteristic sharp odor of chlorine can be noticeable even when the amount of chlorine in the air is small, it is possible to get out of the gas area before serious harm is suffered. This feature of chlorine gas helps reduce potential operator exposure as compared with other hazardous gases such as carbon monoxide, which is odorless and gives no warning of exposure, and hydrogen sulfide, which impairs your sense of smell in a short time.

Inhaling chlorine causes general restlessness, panic, severe irritation of the throat, sneezing, and production of much saliva. These symptoms are followed by coughing, retching and vomiting, and difficulty in breathing. Chlorine is particularly irritating to persons suffering from asthma and certain types of chronic bronchitis. Liquid chlorine causes severe irritation and blistering on contact with the skin. Regular exposure to chlorine can produce chronic effects such as permanent damage to lung tissue.

5.62 Protect Yourself From Chlorine

Every person working with chlorine should know the proper ways to handle it, should be trained in the use of self contained breathing apparatus (SCBA), and should know what to do in case of emergencies. Wear a SCBA which protects your face, eyes and nose. The clothing of persons exposed to chlorine can be saturated with chlorine which will irritate the skin if exposed to moisture or sweat. These people should not enter confined spaces before their clothing is purged of chlorine (stand out in the open air for awhile). This is particularly applicable to police and fire department personnel who leave the scene of a chlorine leak and ride back to their stations in closed vehicles. Suitable protective clothing for working in an atmosphere containing chlorine include disposable rainsuits with hoods to protect your body, head and limbs and rubber boots.

WARNING

CANISTER TYPE **'GAS MASKS'** ARE USUALLY **INADEQUATE** AND **INEFFECTIVE** IN SITUATIONS WHERE CHLORINE LEAKS OCCUR AND ARE THEREFORE NOT RECOMMENDED FOR USE UNDER ANY CIRCUMSTANCES. **SELF-CONTAINED AIR OR OXYGEN SUPPLY TYPE BREATHING APPARATUS ARE RECOMMENDED.** OPERATORS SERVING ON "EMERGENCY CHLORINE TEAMS" MUST BE CAREFULLY SELECTED AND RECEIVE REGULAR APPROVED TRAINING. THEY MUST BE PROVIDED THE PROPER EQUIPMENT WHICH RECEIVES REGULAR MAINTENANCE AND IS READY FOR USE AT ALL TIMES.

TABLE 5.8 PHYSIOLOGICAL RESPONSE TO CONCENTRATIONS OF CHLORINE GAS[a]

Effect	Parts of Chlorine Gas Per Million Parts of Air by Volume (ppm)
Slight symptoms after several hours' exposure	1[b]
Detectable odor	0.3 to 3.5
Noxiousness	5
Throat irritation	15
Coughing	30
Death after a few deep breaths	1000

[a] Adapted from data in U.S. Bureau of Mines TECHNICAL PAPER 248 (1955).

[b] OSHA regulations specify that exposure to chlorine shall at *NO* time exceed 1 ppm.

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[28] *Write to: The Chlorine Institute, Inc., 342 Madison Avenue, New York, New York 10017. Price $5.00.*

Self-contained air supply and demand-breathing equipment must fit properly and be used properly. Pressure demand and rebreather kits may be safer. Pressure demand units use more air from the air bottle which reduces the time a person may work on a leak.

Before entering an area with a chlorine leak, wear protective clothing. Gloves and a rubber suit will prevent chlorine from contacting the sweat on your body and forming hydrochloric acid. Rubber suits are very cumbersome, but should be worn when the weather it hot and humid and the chlorine concentration is high. Otherwise, use your own judgment regarding whether or not to wear protective clothing.

The best protection that one can have when dealing with chlorine is to respect it. Each individual should practice rules of safe handling and good PREVENTIVE MAINTENANCE.

PREVENTION IS THE BEST EMERGENCY TOOL YOU HAVE.

PLAN AHEAD.

1. Have your fire department tour the area so that they know where the facilities are located. Give them a clearly marked map indicating the location of the chlorine storage area, chlorinators, and gas masks.
2. Have emergency drills using chlorine gas masks and chlorine repair kits.
3. Have a supply of ammonia available to detect chlorine leaks.
4. Write emergency procedures.

   Prepare a CHLORINE EMERGENCY LIST of names or companies and phone numbers of persons to call during an emergency. This list should include:

   a. Fire department,
   b. Chlorine emergency personnel, and
   c. Chlorine supplier.
5. Follow established procedures during all emergencies.
   a. Never work alone during chlorine emergencies.
   b. Obtain help immediately and quickly repair the problem. PROBLEMS DO NOT GET BETTER.
   c. Only authorized and properly trained persons with adequate equipment should be allowed in the danger area to correct the problem.
   d. If you are caught in a chlorine atmosphere without a gas mask, shallow breathing is safer than breathing deeply. Recovery depends upon the duration and amount of chlorine inhaled, so it is important to keep that amount as small as possible.
   e. If you discover a chlorine leak, leave the area immediately unless it is a very minor leak. Small leaks can be found by using a rag soaked with ammonia. A white gas will form near the leak so it can be located and corrected.
   f. Use approved respiratory protection and wear disposable clothing when repairing a chlorine test.
   g. Notify your police department that you need help if it becomes necessary to stop traffic on roads and to evacuate persons in the vicinity of the chlorine leak.
6. Develop emergency evacuation procedures for use during a serious chlorine leak. Coordinate these procedures with your police department and other officials.
7. Post emergency procedures in all operating areas.
8. Inspect equipment and routinely make any necessary repairs.
9. At least twice weekly, inspect area where chlorine is stored and where chlorinators are located. Remove all obstructions from the area.
10. Schedule routine maintenance on ALL chlorine equipment at least once every six months or more frequently.
11. Have health appraisal for employees on chlorine emergency duty. No one with heart and respiratory problems should be allowed on emergency teams.

REMEMBER:

Small amounts of chlorine cause large problems. Leaks never get better.

5.63 First Aid Measures

MILD CASES

Whenever you have a mild case of chlorine exposure (which does happen from time to time around chlorination equipment), you should first leave the contaminated area. Move slowly, breathe lightly without exertion, remain calm, keep warm and resist coughing. Notify other operators and have them repair the leak immediately.

If clothing has been contaminated, remove as soon as possible. Otherwise the clothing will continue to give off chlorine gas which will irritate the body even after leaving the contaminated area. Immediately wash off area affected by chlorine. Shower and put on clean clothes.

If victim has slight throat irritation, immediate relief can be accomplished by drinking milk. Drinking spirits of peppermint also will help reduce throat irritation. See a physician.

EXTREME CASES

1. Follow established emergency procedures.
2. Always use proper safety equipment. Do not enter area without a self-contained breathing apparatus.
3. Remove patient from affected area immediately.
4. First aid:
   a. Remove contaminated clothes to prevent clothing giving off chlorine gas which will irritate the body.
   b. Keep patient warm and cover with blankets if necessary.
   c. Place patient in a comfortable position on back.
   d. EYES!

      If even a small amount of chlorine gets into the eyes, they should be flushed with water. The flushing should continue so that all traces of chlorine are flushed from the eyes.
5. See a physician.

5.64 Hypochlorite Safety

Hypochlorite does not present the hazards that gaseous chlorine does and therefore is safer to handle. When spills occur, wash with large volumes of water. The solution is messy to handle. Hypochlorite causes damage to your eyes and skin upon contact. Immediately wash affected areas thoroughly with water. Consult a physician if the area appears burned. Hypochlorite solutions are very corrosive. Hypochlorite compounds are non-flammable; however, they can cause fires when the come in contact with organics or other easily oxidizable substances.

5.65 Chlorine Dioxide Safety

Chlorine dioxide is generated in much the same manner as chlorine and should be handled with the same care. Of special concern is the use of sodium chlorite to generate chlorine dioxide. Sodium chlorite is very combustible around organic compounds. Whenever spills occur, sodium chlorite must be neutralized with anhydrous sodium sulfite. Combustible materials (including gloves) should not be worn when handling sodium chlorite. If sodium chlorite comes in contact with clothing, the clothes should be removed immediately and soaked in water to remove all traces of sodium chlorite or the clothes should be burned immediately.

5.66 Operator Safety Training

Training is a concern to everyone, especially when your safety and perhaps your life is concerned. Every utility agency should have an operator chlorine safety training program which introduces new operators to the program and updates previously trained operators. As soon as a training session ends, obsolescence begins. People will forget what they have learned if they don't use and practice their knowledge and skills. Operator turnover can dilute a well-trained staff. New equipment and also new techniques and procedures can dilute the readiness of trained operators. An on-going training program can consist of a monthly luncheon seminar, a monthly safety bulletin that is to be read by every operator, and outside speakers can be brought in to reinforce and refresh specific elements of a safety training program.

The American Water Works Association (AWWA) is an excellent source of training materials for safety programs. Films are available from AWWA for rental fees of around $15.00. Typical films include "A Demonstration of the A, B and C Emergency Kits." This film illustrates the application of the Chlorine Institute's A, B and C emergency repair devices. "Safe Handling of Chlorine" is a film about procedures for handling chlorine cylinders, ton containers, tank cars and barges. Also discussed are appropriate materials for construction, pumping chlorine, checking storage tanks, operating vaporizers, repacking valves, and training operators how to safely handle chlorine. To obtain these and other films, write or call AWWA, Library, 6666 West Quincy Avenue, Denver, Colorado 80235; phone 303-794-7711.

5.67 CHEMTREC (800-424-9300)

Safely handling chemicals used in daily water treatment is an operator's responsibility. However, if the situation ever gets out of hand, there are emergency teams that will respond with help anywhere there is an emergency. If an emergency does develop in your plant and you need assistance, call CHEMTREC (Chemical Transportation Emergency Center) for assistance. CHEMTREC will provide immediate advice for those at the scene of an emergency and then quickly alert experts whose products are involved for more detailed assistance and appropriate follow-up.

CHEMTREC'S EMERGENCY TOLL-FREE PHONE NUMBER IS 800-424-9300.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 279.

5.6A What properties make chlorine gas so hazardous?

5.6B What type of breathing apparatus is recommended when repairing a chlorine leak?

5.6C What first aid measures should be taken if a person comes in contact with chlorine gas?

5.6D What would you do if hypochlorite came in contact with your hand?

5.7 CHLORINATION ARITHMETIC

All calculations in this section can be performed by addition, subtraction, multiplication and division on a pocket electronic calculator.

FORMULAS

There are two approaches to calculating chlorine doses in milligrams per liter. They are both the same, but have a slightly different form. From the basic equation on page 512,

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal}),$$

we can rearrange the equation and solve for the dose in milligrams per liter.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine, lbs}}{(\text{Volume, M Gal})(8.34\text{ lbs/day})}$$

If the basic equation is expressed as a chemical feeder setting in pounds per day, then the flow would be in million gallons per day (MGD).

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

Both of the above equations are also in terms of pounds or pounds per day of chlorine per million pounds or million pounds per day of water.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine, lbs/day}}{\text{Water, Million lbs/day}}$$

5.70 Disinfection of Facilities

5.700 Wells and Pumps

EXAMPLE 8

How many gallons of 5.25 percent sodium hypochlorite will be needed to disinfect a well with an 18-inch diameter casing and well screen? The well is 300 feet deep and there is 200 feet of water in the well. Use an initial chlorine dose of 100 mg/*L*.

Known		Unknown
Hypochlorite, %	= 5.25%	5.25% Hypochlorite, gal
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Well Casing, in	= 18 in	
Well Depth, ft	= 300 ft	
Water Depth, ft	= 200 ft	

1. Find the volume of water in the well in gallons.

$$\text{Well Vol, Gal} = (0.785)(\text{Diameter, ft})^2(\text{Water Depth, ft})(7.48 \text{ gal/cu ft})$$

$$= \frac{(0.785)(18 \text{ in})^2(200 \text{ ft})(7.48 \text{ gal/cu ft})}{144 \text{ sq in/sq ft}}$$

$$= 2642 \text{ gal}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})$$

$$= (0.002642 \text{ M Gal})(100 \text{ mg}/L)(8.34 \text{ lbs/gal})$$

$$= 2.2 \text{ lbs chlorine}$$

3. Calculate the gallons of 5.25 percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34 \text{ lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(2.2 \text{ lbs})(100\%)}{(8.34 \text{ lbs/gal})(5.25\%)}$$

$$= 5.0 \text{ gallons}$$

Five gallons of 5.25 percent sodium hypochlorite should do the job.

5.701 Mains

EXAMPLE 9

A section of an old 8-inch water main has been replaced and a 350-foot section of pipe needs to be disinfected. An initial chlorine dose of 400 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the three-hour disinfection period. How many gallons of 5.25 percent sodium hypochlorite solution will be needed?

Known		Unknown
Diameter of Pipe, in	= 8 in	5.25% Hypochlorite, gallons
or 8 in/12 in/ft	= 0.67 ft	
Length of Pipe, ft	= 350 ft	
Chlorine Dose, mg/*L*	= 400 mg/*L*	
Hypochlorite, %	= 5.25%	

1. Calculate the volume of water in the pipe in gallons.

$$\text{Pipe Volume, gallons} = (0.785)(\text{Diameter, ft})^2(\text{Length, ft})(7.48 \text{ gal/cu ft})$$

$$= (0.785)(0.67 \text{ ft})^2(350 \text{ ft})(7.48 \text{ gal/cu ft})$$

$$= 923 \text{ gallons of water}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})$$

$$= (0.000923 \text{ M Gal})(400 \text{ mg}/L)(8.34 \text{ lbs/gal})$$

$$= 3.08 \text{ lbs/chlorine}$$

3. Calculate the gallons of 5.25 percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34 \text{ lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(3.08 \text{ lbs})(100\%)}{(8.34 \text{ lbs/gal})(5.25\%)}$$

$$= 7.0 \text{ gallons}$$

Seven gallons of 5.25 percent solution of sodium hypochlorite should do the job.

5.702 Tanks

EXAMPLE 10

An existing service storage reservoir has been taken out of service for inspection, maintenance and repairs. The reservoir needs to be disinfected before being placed back on line. The reservoir is 6 feet deep, 10 feet wide and 25 feet long. An initial chlorine dose of 100 mg/*L* is expected to maintain a chlorine residual of over 50 mg/*L* during the 24-hour disinfection period. How many gallons of 5.25 percent sodium hypochlorite solution will be needed?

Known		Unknown
Tank Depth, ft	= 6 ft	5.25% Hypochlorite, gal
Tank Width, ft	= 10 ft	
Tank Length, ft	= 25 ft	
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Hypochlorite, %	= 5.25%	

1. Calculate the volume of water in the tank in gallons.

$$\text{Tank Volume, gallons} = (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})(7.48 \text{ gal/cu ft})$$

$$= (25 \text{ ft})(10 \text{ ft})(6 \text{ ft})(7.48 \text{ gal/cu ft})$$

$$= 11{,}220 \text{ gallons}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Vol Water, M Gal})(\text{Chlorine Dose, mg}/L)(8.34 \text{ lbs/gal})$$

$$= (0.01122 \text{ M Gal})(100 \text{ mg}/L)(8.34 \text{ lbs/gal})$$

$$= 9.36 \text{ lbs chlorine}$$

3. Calculate the gallons of 5.25 percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34 \text{ lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(9.36 \text{ lbs})(100\%)}{(8.34 \text{ lbs/gal})(5.25\%)}$$

$$= 21.4 \text{ gallons}$$

Twenty-two gallons of 5.25 percent sodium hypochlorite solution should do the job.

5.71 Disinfection of Water from Wells

5.710 Chlorine Dose

EXAMPLE 11

A chlorine demand test from a well water sample produced a result of 1.2 mg/*L*. The water supplier would like to maintain a chlorine residual of 0.2 mg/*L* throughout the system. What should be the chlorine dose in mg/*L* from either a chlorinator or hypochlorinator?

Known		Unknown
Chlorine Demand, mg/*L*	= 1.2 mg/*L*	Chlorine Dose, mg/*L*
Chlorine Residual, mg/*L*	= 0.2 mg/*L*	

Calculate the chlorine dose in mg/*L*.

$$\text{Chlorine Dose, mg/}L = \text{Chlorine Demand, mg/}L + \text{Chlorine Residual, mg/}L$$

$$= 1.2\text{ mg/}L + 0.2\text{ mg/}L$$

$$= 1.4\text{ mg/}L$$

NOTE: Be sure to check the chlorine residual regularly throughout the system. If the residual is low or there are coliforms present in the test results, then the residual should be increased.

5.711 Chlorinator

EXAMPLE 12

A deep-well turbine pump is connected to a hydropneumatic tank. Under normal operating heads, the pump delivers 500 GPM. If the desired chlorine dosage is 3.5 mg/*L*, what should be the setting on the rotameter for the chlorinator (lbs chlorine per 24 hours)?

Known		**Unknown**
Pump Flow, GPM	= 500 GPM	Rotameter Setting, lbs chlorine/24 hours
Chlorine Dose, mg/*L*	= 3.5 mg/*L*	

1. Convert pump flow to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{(500\text{ GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hrs/day})}{1{,}000{,}000}$$

$$= 0.72\text{ MGD}$$

2. Calculate the rotameter setting in pounds of chlorine per 24 hours.

$$\text{Rotameter Setting, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$= (0.72\text{ MGD})(3.5\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 21.0\text{ lbs chlorine/day}$$

$$= 21.0\text{ lbs chlorine/24 hours}$$

EXAMPLE 13

Using the results from EXAMPLE 12 (a chlorinator setting of 21 lbs per 24 hours), how many pounds of chlorine would be used in one month if the pump hour meter shows the pump operates an average of 20 hours per day? The chlorinator operates only when the pump operates. How many 150-pound cylinders will be needed per month?

Known		**Unknown**
Chlorinator Setting, lbs/day	= 21 lbs/day	1. Chlorine Used, lbs/mo
Pump Operation, hrs/day	= 20 hrs/day	2. Cylinders Needed, no/mo
Chlorine Cylinders, lbs/cyl	= 150 lbs/cyl	

1. Calculate the chlorine used in pounds per month.

$$\text{Chlorine Used, lbs/mo} = \frac{(\text{Cl Setting, lbs/day})(\text{Operation, hr/day})(30\text{ days/mo})}{24\text{ hrs/day}}$$

$$= \frac{(21\text{ lbs/day})(20\text{ hrs/day})(30\text{ days/mo})}{24\text{ hrs/day}}$$

$$= 525\text{ lbs/mo}$$

2. Determine the number of 150-pound cylinders used per month.

$$\text{Cylinders Needed, no/mo} = \frac{\text{Chlorine Used, lbs/mo}}{150\text{ lbs Chlorine/cylinder}}$$

$$= \frac{525\text{ lbs Cl/mo}}{150\text{ lbs Cl/cylinder}}$$

$$= 3.5\text{ cylinders/month}$$

EXAMPLE 14

A deep-well turbine pump delivers 400 GPM throughout a 24-hour period. The weight of chlorine in a 150-pound cylinder was 123 pounds at the start of the time period and 109 pounds at the end of the 24 hours. What was the chlorine dose rate in mg/*L*?

Known		**Unknown**
Pump Flow, GPM	= 400 GPM	Chlorine dose, mg/*L*
Time Period, hrs	= 24 hrs	
Chlorine Wt at Start, lbs	= 123 lbs	
Chlorine Wt at End, lbs	= 109 lbs	

1. Convert flow of 400 GPM to MGD.

$$\text{Flow, MGD} = \frac{(400\text{ gal/min})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

$$= 0.576\text{ MGD}$$

2. Calculate the chlorine dose rate in mg/*L*.

$$\text{Chlorine Dose, mg/}L = \frac{\text{Chlorine Used, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{(123\text{ lbs} - 109\text{ lbs})/1\text{ day}}{(0.576\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{14\text{ lbs chlorine/day}}{(0.576\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{2.9\text{ lbs Chlorine}}{1\text{ M lbs Water}}$$

$$= 2.9\text{ mg/}L$$

5.712 Hypochlorinator

EXAMPLE 15

Water from a well is being treated by a hypochlorinator. If the hypochlorinator is set at a pumping rate of 50 gallons per day (GPD) and uses a 3 percent available hypochlorite solution, what is the chlorine dose rate in mg/*L* if the pump delivers 350 GPM?

Known		**Unknown**
Hypochlorinator, GPD	= 50 GPD	Chlorine Dose, mg/*L*
Hypochlorite, %	= 3%	
Pump, GPM	= 350 GPM	

1. Convert the pumping rate to MGD.

$$\text{Pumping Rate, MGD} = \frac{(350\text{ GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

$$= 0.50\text{ MGD}$$

2. Calculate the chlorine dose rate in pounds per day.

$$\text{Chlorine Dose, lbs/day} = \frac{\text{(Flow, gal/day)(Hypochlorite, \%)(8.34 lbs/gal)}}{100\%}$$

$$= \frac{\text{(50 gal/day)(3\%)(8.34 lbs/gal)}}{100\%}$$

$$= \text{12.5 lbs/day}$$

3. Calculate the chlorine dose in mg/*L*.

$$\text{Chlorine Dose, mg/}L = \frac{\text{Chlorine Dose, lbs/day}}{\text{(Flow, MGD)(8.34 lbs/gal)}}$$

$$= \frac{\text{12.5 lbs chlorine/day}}{\text{(0.50 M gal/day)(8.34 lbs/gal)}}$$

$$= \text{3 lbs chlorine/M lbs water}$$

$$= 3\ \text{mg/}L$$

EXAMPLE 16

Water pumped from a well is disinfected by a hypochlorinator. During a one-week time period, the water meter indicated that 1,098,000 gallons of water were pumped. A 2.0 percent sodium hypochlorite solution is stored in a 2.5-foot diameter plastic tank. During this one-week time period, the level of hypochlorite in the tank dropped 18 inches (1.50 ft). What was the chlorine dose in mg/*L*?

Known		Unknown
Water Treated, M Gal	= 1.098 M Gal	Chlorine Dose, mg/*L*
Hypochlorite, %	= 2.0%	
Hypochlorite Tank D, ft	= 2.5 ft	
Hypochlorite Used, ft	= 1.5 ft	

1. Calculate the pounds of water disinfected.

$$\text{Water, lbs} = \text{(Water Treated, M Gal)(8.34 lbs/gal)}$$

$$= \text{(1.098 M Gal)(8.34 lbs/gal)}$$

$$= \text{9.16 M lbs water}$$

2. Calculate the volume of hypochlorite solution used in gallons.

$$\text{Hypochlorite, gal} = \text{(0.785)(Diameter, ft)}^2\text{(Drop, ft)(7.48 gal/cu ft)}$$

$$= \text{(0.785)(2.5 ft)}^2\text{(1.5 ft)(7.48 gal/cu ft)}$$

$$= \text{55.0 gallons}$$

3. Determine the pounds of chlorine used to treat the water.

$$\text{Chlorine, lbs} = \text{(Hypochlorite, gal)}\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)\text{(8.34 lbs/gal)}$$

$$= \text{(55.0 gal)}\left(\frac{2.0\%}{100\%}\right)\text{(8.34 lbs/gal)}$$

$$= \text{9.17 lbs chlorine}$$

4. Calculate the chlorine dose in mg/*L*.

$$\text{Chlorine Dose, mg/}L = \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}}$$

$$= \frac{\text{9.17 lbs Chlorine}}{\text{9.16 M lbs Water}}$$

$$= \frac{\text{1.0 lbs Chlorine}}{\text{1 M lbs water}}$$

$$= 1.0\ \text{mg/}L$$

EXAMPLE 17

Estimate the required concentration of a hypochlorite solution (%), if a pump delivers 600 GPM from a well. The hypochlorinator can deliver a maximum of 120 GPD and the desired chlorine dose is 1.8 mg/*L*.

Known		Unknown
Pump Flow, GPM	= 600 GPM	Hyporchlorite Strength, %
Hypo Cl Flow, GPD	= 120 GPD	
Chlorine Dose, mg/*L*	= 1.8 mg/*L*	

1. Calculate the flow of water treated in million gallons per day.

$$\text{Water Treated, M gal/day} = \frac{\text{(600 GPM)(1 Million)(60 min/hr)(24 hrs/day)}}{1{,}000{,}000}$$

$$= \text{0.864 MGD}$$

2. Determine the pounds of chlorine required per day.

$$\text{Chlorine Required, lbs/day} = \text{(Flow, MGD)(Dose, mg/}L\text{)8.34 lbs/gal)}$$

$$= \text{(0.864 MGD)(1.8 mg/}L\text{)(8.34 lbs/gal)}$$

$$= \text{13.0 lbs chlorine/day}$$

3. Calculate the hypochlorite solution strength as a percent.

$$\text{Hypochlorite Strength, \%} = \frac{\text{(Chlorine Required, lbs/day)(100\%)}}{\text{(Hypochlorinator Flow, GPD)(8.34 lbs/gal)}}$$

$$= \frac{\text{(13.0 lbs/day)(100\%)}}{\text{(120 GPD)(8.34 lbs/gal)}}$$

$$= 1.3\%$$

EXAMPLE 18

A hypochlorite solution for a hypochlorinator is being prepared in a 55-gallon drum. If 10 gallons of 5 percent hypochlorite is added to the drum, how much water should be added to the drum to produce a 1.3 percent hypochlorite solution?

Known		Unknown
Drum Capacity, gal	= 55 gal	Water Added, gal
Hypochlorite, gal	= 10 gal	
Hypochlorite, %	= 5%	
Desired Hypo, %	= 1.3%	

Calculated the volume of water to be added in gallons.

$$\text{Desired Hypo, \%} = \frac{\text{(Hypo, gal)(Hypo, \%)}}{\text{Hypo, gal + Water Added, gal}}$$

Rearrange the terms in the equation.

$$\text{(Desired Hypo, \%)(Hypo, gal + Water Added, gal)} = \text{(Hypo, gal)(Hypo, \%)}$$

$$\text{(Desired Hypo, \%)(Hypo, gal)} + \text{(Desired Hypo, \%)(Water Added, gal)} = \text{(Hypo, gal)(Hypo, \%)}$$

$$\text{(Desired Hypo, \%)(Water Added, gal)} = \text{(Hypo, gal)(Hypo, \%)} - \text{(Desired Hypo, \%)(Hypo, gal)}$$

$$\text{Water Added, gal} = \frac{\text{(Hypo, gal)(Hypo, \%)} - \text{(Desired Hypo, \%)(Hypo, gal)}}{\text{Desired Hypo, \%}}$$

$$= \frac{\text{(10 gal)(5\%)} - \text{(1.3\%)(10 gal)}}{1.3\%}$$

$$= \frac{50 - 13}{1.3}$$

$$= \text{28.5 gallons of water}$$

Add 28.5 gallons of water to the 10 gallons of 5 percent hypochlorite in the drum.

~~PLUS EQUALS~~
% — MINUS

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 279.

5.7A A section of 12-inch water main has been repaired and a 400-ft section of pipe needs to be disinfected. An initial chlorine dose of 450 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the three-hour disinfection period. How many gallons of 5 percent sodium hypochlorite solution will be needed?

5.7B Estimate the chlorine demand of a water that is dosed at 2.0 mg/*L*. The chlorine residual is 0.2 mg/*L* after a 30-minute contact period.

5.7C What should be the setting on a chlorinator (lbs chlorine per 24 hours) if a pump usually delivers 600 GPM and the desired chlorine dosage is 4.0 mg/*L*?

5.7D Water from a well is being disinfected by a hypochlorinator. If the hypochlorinator is set at a pumping rate of 60 gallons per day (GPD) and uses a 2 percent available chlorine solution, what is the chlorine dose rate in mg/*L*? The pump delivers 400 GPM.

5.8 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A.9, "Steps in Solving Problems." Also work the example problems and check the arithmetic using your calculator.

In Section A.13, "Typical Small Water System Operation Problems," read and work the problems in Section A.134, "Disinfection."

5.9 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 10, "Chlorination."
2. *TEXAS MANUAL*, Chapter 10, "Disinfection of Water."
3. *CHLORINE MANUAL*, The Chlorine Institute, Inc., 342 Madison Avenue, New York, N.Y. 10173. Price, $5.00.
4. *CHLORINE MANUAL*, Chlor-Alkali Business Unit, Chemical Division, PPG Industries Inc., One Gateway Center, Pittsburgh, Pennsylvania 15222
5. *CHLORINE SAFE HANDLING*, Chlor-Alkali Business Unit, Chemical Division, PPG Industries Inc., One Gateway Center, Pittsburgh, Pennsylvania 15222.
6. *BASIC GAS CHLORINATION WORKSHOP MANUAL*. Obtain from Training and Certification Section, Ministry of the Environment, 135 St. Clair Avenue West, Toronto 7, Ontario, M4V 1P5 CANADA.
7. *AWWA STANDARD FOR DISINFECTION WATER MAINS*. C601-81. Obtain from Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 43601. Price to members, $7.00; nonmembers, $8.50.
8. *AWWA STANDARD FOR DISINFECTING WATER STORAGE FACILITIES*, D105-80. Obtain from Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 44105. Price to members, $5.00; nonmembers, $6.50.

5.10 ACKNOWLEDGMENT

Mr. Malcolm P. Dalton, General Manager, and Mr. James F. Brace, Staff Assistant, Navajo Tribal Utility Authority, provided many helpful contributions to all aspects of safety throughout this entire manual.

End of Lesson 2 of 2 Lessons on DISINFECTION

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. DISINFECTION

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 280. The problem numbering continues from Lesson 1.

8. What procedures would you follow to safely handle chlorine cylinders?
9. What precautions would you take when shutting down a hypochlorinator to make repairs for a short duration?
10. How would you determine whether or not the chlorine feed rate of a chlorinator needs adjustment?
11. How would you determine the desired strength of a hypochlorite solution in the solution tank for effective operation of a hypochlorinator?
12. Why is safety equipment needed when repairing a chlorine leak?
13. How would you detect a chlorine leak?
14. What would you do if you could not repair a broken chlorinator quickly?
15. Why should clothing be removed from a person who has been in an area contaminated with liquid or gaseous chlorine?

SUGGESTED ANSWERS

Chapter 5. DISINFECTION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 234.

5.0A Pathogenic organisms are disease-producing organisms.

5.0B Disinfection is the selective destruction of pathogenic organisms.

5.0C The U.S. Environmental Protection Agency establishes drinking water standards.

5.0D MCL stands for **M**aximum **C**ontaminant **L**evel.

Answers to questions on page 237.

5.1A Relatively cold water requires longer disinfection time or greater quantities of disinfectants.

5.1B Most disinfectants are more effective in water with a pH around 7.0 than in water above a pH of 8.0.

5.1C The greater the number and type of microorganisms present, the greater may be the adverse influence on the effectiveness of the disinfectant.

Answers to questions on page 238.

5.2A Physical agents that have been used for disinfection other than chlorine include (1) ultraviolet rays, (2) heat and (3) ultra sonic waves.

5.2B Chemical agents that have been used for disinfection other than chlorine include (1) iodine, (2) bromine, (3) bases (sodium hydroxide and lime), and (4) ozone.

5.2C A major limitation to the use of ozone is the inability of ozone to provide a residual in the distribution system.

Answers to questions on page 239.

5.2D Hydrogen sulfide and ammonia are two inorganic reducing chemicals that react rapidly with chlorine.

5.2E $$\begin{matrix}\text{Chlorine} \\ \text{Demand, mg}/L\end{matrix} = \begin{matrix}\text{Chlorine} \\ \text{Dose, mg}/L\end{matrix} - \begin{matrix}\text{Chlorine} \\ \text{Residual, mg}/L\end{matrix}$$

5.2F $$\begin{matrix}\text{Chlorine} \\ \text{Dose, mg}/L\end{matrix} = \begin{matrix}\text{Chlorine} \\ \text{Demand, mg}/L\end{matrix} + \begin{matrix}\text{Chlorine} \\ \text{Residual, mg}/L\end{matrix}$$

Answers to questions on page 241.

5.2G The higher the pH level, the greater the percent of OCl^-.

5.2H Chlorine gas tends to lower the pH while hypochlorite tends to increase the pH.

Answers to questions on page 246.

5.3A When disinfecting a well, the well, pump, screen and aquifer around the well all should be disinfected because they all could have been contaminated during construction and are potential sources of contamination.

5.3B The chlorine solution should be applied to the well by injecting the chlorine down the pump down column pipe rather than injected through the vent pipe.

5.3C A well has been successfully disinfected if the results of a bacteriological analysis for total coliforms are negative (no coliforms.)

Answers to questions on page 251.

5.3D Water mains can be kept clean during construction and repair by keeping material such as dirt, construction materials, animals, rodents and dirty water out of the mains. Inspecting the pipes when laid, keeping trenches dry and installing watertight plugs all help to keep pipes clean.

5.3E Areas in a water main that require an extra effort for successful disinfection include fittings, valves and air pockets where chlorine might not come in contact with the surface.

5.3F Three forms of chlorine used for disinfection include:

1. Chlorine gas (liquid chlorine in cylinders),
2. Calcium hypochlorite, and
3. Sodium hypochlorite.

5.3G Water used for disinfection that has a high chlorine residual may be disposed of in sanitary sewers, storm sewers, or on land, but should not be disposed of in a manner that will cause an adverse impact on the environment.

5.3H Before a water main is disinfected, the main should be flushed for at least 30 minutes with a flushing velocity of 2.5 ft/sec.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 257.

5.4A The two major types of chlorine feeders are (1) hypochlorinators and (2) chlorinators.

5.4B Chlorine booster pumps are needed on most well applications to overcome the higher water pump discharge pressures.

5.4C The maximum rate of chlorine removal from a 150-pound cylinder is 40 pounds of chlorine per day.

Answers to questions on page 265.

5.4D The chemical feed of a hypochlorinator is adjusted until an adequate chlorine residual exists throughout the system and coliform test results are negative.

5.4E The level of the hypochlorite solution tank should be read at the same time every day.

5.4F The strength of the hypochlorite solution in the solution tank is adjusted so that the frequency of the strokes or pulses from the solution feed pump will be close together. This insures that chlorine will be fed continuously to the water treated.

5.4G Maintenance usually required of hypochlorinators includes oil changes and lubrication.

Answers to questions on page 268.

5.4H Before attempting to locate and repair a chlorine gas leak, you should have protective clothing (gloves and rubber suit) and self-contained pressure-demand air supply.

5.4I A chlorine leak can be detected by holding an ammonia soaked rag near suspected leaks. A white cloud will reveal the location of the leak.

5.4J If a chlorinator cannot be repaired quickly, shut off the water supply so that unchlorinated or contaminated water will not be delivered to consumers. Also shut off chlorine supply so chlorine line can be purged.

5.4K The two most common water quality tests run on samples of water from a water supply system are (1) chlorine residual and (2) coliform tests.

Answers to questions on page 268.

5.5A Chlorine residual is measured in treated water by the use of (1) amperometric titration and (2) DPD colorimetric method.

5.5B Residual chlorine measurements of treated water should be taken three times per day on small systems and once every two hours on large systems.

Answers to questions on page 273.

5.6A Chlorine gas is extremely toxic and corrosive in most atmospheres.

5.6B A properly fitting self-contained air or oxygen supply type of breathing apparatus, pressure demand, or a rebreather kit is recommended when repairing a chlorine leak.

5.6C First aid measures depend on the severity of the contact. Remove the victim from the gas area and keep the victim warm and quiet. Call a doctor and the fire department immediately. Keep the patient breathing.

5.6D Whenever hypochlorite comes in contact with your hand, immediately wash the hypochlorite off and thoroughly wash your hand. Consult a physician if the area appears burned.

Answers to questions on page 277.

5.7A

Known	Unknown
Diameter of Pipe, in = 12 in	Hypochlorite, gallons
or ft = 1.0 ft	
Length of Pipe, ft = 400 ft	
Chlorine Dose, mg/L = 450 mg/L	
Hypochlorite, % = 5%	

1. Calculate the volume of water in the pipe in gallons.

$$\text{Pipe Volume, gallons} = (0.785)(\text{Diameter, ft})^2(\text{Length, ft})(7.48\text{ gal/cu ft})$$
$$= (0.785)(1.0\text{ ft})^2(400\text{ ft})(7.48\text{ gal/cu ft})$$
$$= 2349\text{ gallons}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Vol Water, M Gal})(\text{Chlorine Dose, mg}/L)(8.34\text{ lbs/gal})$$
$$= (0.002349\text{ M Gal})(450\text{ mg}/L)(8.34\text{ lbs/gal})$$
$$= 8.82\text{ lbs chlorine}$$

3. Calculate the gallons of 5 percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\text{ lbs/gal})(\text{Hypochlorite, }\%)}$$
$$= \frac{(8.82\text{ lbs Chlorine})(100\%)}{(8.34\text{ lbs/gal})(5\%)}$$
$$= 21.2\text{ gallons}$$

A little over 21 gallons of hypochlorite should do the job.

5.7B

Known	Unknown
Chlorine Dose, mg/L = 2.0 mg/L	Chlorine Demand, mg/L
Chlorine Residual, mg/L = 0.2 mg/L	

Calculate the chlorine demand in mg/L.

$$\text{Chlorine Demand, mg}/L = \text{Chlorine Dose, mg}/L - \text{Chlorine Residual, mg}/L$$
$$= 2.0\text{ mg}/L - 0.2\text{ mg}/L$$
$$= 1.8\text{ mg}/L$$

5.7C

Known	Unknown
Pump Flow, GPM = 600 GPM	Chlorinator Setting, lbs Chlorine/24 hrs
Chlorine Dose, mg/L = 4.0 mg/L	

1. Convert pump flow to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{(600\text{ GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$
$$= 0.864\text{ MGD}$$

2. Calculate the chlorinator setting in pounds of chlorine per 24 hours.

$$\text{Chlorinator Setting, lbs/24 hrs} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$
$$= (0.864\text{ MGD})(4.0\text{ mg}/L)(8.34\text{ lbs/gal})$$
$$= 28.8\text{ lbs chlorine/day}$$
$$= 28.8\text{ lbs chlorine/24 hours}$$

5.7D

Known	Unknown
Hypochlorinator, GPD = 60 GPD	Chlorine Dose, mg/L
Hypochlorite, % = 2%	
Pump, GPM = 400 GPM	

1. Convert the pumping rate to MGD.

$$\text{Pumping Rate, MGD} = \frac{(400\text{ GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$
$$= 0.58\text{ MGD}$$

2. Calculate the chlorine dose rate in pounds per day.

$$\text{Chlorine Dose, lbs/day} = \frac{(\text{Flow, gal/day})(\text{Hypochlorite, }\%)(8.34\text{ lbs/gal})}{100\%}$$
$$= \frac{(60\text{ GPD})(2\%)(8.34\text{ lbs/gal})}{100\%}$$
$$= 10.0\text{ lbs chlorine/day}$$

3. Calculate the chlorine dose in mg/L.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine Dose, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$
$$= \frac{10.0\text{ lbs chlorine/day}}{(0.58\text{ MGD})(8.34\text{ lbs/gal})}$$
$$= 2.1\text{ lbs chlorine/M lbs water}$$
$$= 2.1\text{ mg}/L$$

OBJECTIVE TEST

CHAPTER 5. DISINFECTION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True — False

1. Disinfection is intended to kill all pathogenic organisms.
   1. True
   2. False
2. Chlorination is an effective means of sterilizing water.
   1. True
   2. False
3. The resistance of microorganisms to specific disinfectants varies greatly.
   1. True
   2. False
4. The lower the temperature of the water, the greater the effectiveness of the disinfectant.
   1. True
   2. False
5. Hypochlorite (OCl^-) has a greater disinfection potential than hypochlorous acid ($HOCl$).
   1. True
   2. False
6. Flushing is an effective way to disinfect water mains.
   1. True
   2. False
7. The location of the chlorine injection point in a water system is very important.
   1. True
   2. False
8. Chlorine injected on the suction side of a pump may cause corrosion problems.
   1. True
   2. False
9. Whenever a new chlorine connection is made, always use a new gasket.
   1. True
   2. False
10. The flushing velocity for a water main after disinfection is more important than the flushing velocity before disinfection.
    1. True
    2. False
11. Chlorine gas is safer to handle than hypochlorite when disinfecting water.
    1. True
    2. False
12. Hypochlorite compounds are available in solid form only.
    1. True
    2. False
13. When chlorine gas combines with moisture, the resulting mixture is corrosive.
    1. True
    2. False

14 and 15. The reaction of chlorine gas with water tends to (14)________ the pH of the water while sodium hypochlorite tends to (15)________ the pH.

14. 1. Decrease
    2. Increase
15. 1. Decrease
    2. Increase

Multiple Choice

16. Alum usage can increase virus removals up to ________.
    1. 20%
    2. 50%
    3. 70%
    4. 90%
    5. 99%
17. Drains should be flushed before disinfection by using a flushing velocity of at least ________.
    1. 0.5 ft/sec
    2. 1.0 ft/sec
    3. 1.5 ft/sec
    4. 2.0 ft/sec
    5. 2.5 ft/sec
18. The maximum rate of chlorine removal from a 150-pound cylinder is ________ pounds of chlorine per 24 hours.
    1. 20
    2. 40
    3. 60
    4. 80
    5. 100
19. Which of the following precautions would you take when shutting down a hypochlorinator for a short duration?
    1. Lock out circuits
    2. Obtain another hypochlorinator
    3. Turn off gas
    4. Turn off hypochlorinator
    5. Turn off water supply pump
20. Which of the following are safe procedures for handling chlorine cylinders?
    1. Keep cylinders close to direct heat to prevent freezing
    2. Move cylinders with a properly balanced hand truck
    3. Protective cap should always be in place when moving a cylinder
    4. Roll cylinders in a horizontal position
    5. Store cylinders on their sides

21. Factors influencing disinfection include
    1. Concentration of microorganisms.
    2. Hardness.
    3. pH.
    4. Temperature.
    5. Turbidity.

22. Pathogenic microorganisms are removed by which of the following water treatment processes?
    1. Coagulation
    2. Dilution
    3. Filtration
    4. Membrane filtration
    5. Sedimentation

23. If you were asked to review the specifications for disinfecting a water main by an outside contractor, which of the following items would you be sure were included in the contract specifications?
    1. Form of chlorine to be used
    2. Location of suitable drainage facilities
    3. Method of taking samples
    4. Rates of flushing
    5. Who is responsible for testing samples

24. Which of the following tasks should be checked daily under normal hypochlorinator operating conditions?
    1. Check chemical feed pump operation
    2. Check operation of check valve
    3. Measure chlorine residual in system
    4. Record gallons of water pumped
    5. Record level of solution in hypochlorite tank

25. Which of the following laboratory test results are used to adjust the chlorine dose rate setting on a chlorinator?
    1. Chloride
    2. Chlorine residual
    3. Coliform
    4. Hardness
    5. TDS

26. Chlorine cylinders
    1. Can be handled safely.
    2. Can easily be lifted by one person.
    3. Contain a fusible metal safety plug.
    4. Should be kept away from steam pipes.
    5. Should be moved with the protective cap in place.

27. An operator should never enter a room containing high concentrations of chlorine gas without
    1. A self-contained air supply.
    2. Help standing by.
    3. Notifying proper authorities.
    4. Notifying supervisor.
    5. Protective clothing.

28. What should be the chlorine dose of a water that has a chlorine demand of 2.5 mg/*L* if a residual of 0.4 mg/L is desired?
    1. 2.1 mg/*L*
    2. 2.3 mg/*L*
    3. 2.5 mg/*L*
    4. 2.9 mg/*L*
    5. 3.3 mg/*L*

29. What should be the setting on a chlorinator if a pump usually delivers approximately 700 GPM (assume 1 MGD) and the desired chlorine dose is 4.0 mg/*L*?
    1. 25 lbs chlorine/24 hours
    2. 30 lbs chlorine/24 hours
    3. 33 lbs chlorine/24 hours
    4. 36 lbs chlorine/24 hours
    5. 40 lbs chlorine/24 hours

30. Water from a well is being disinfected by a hypochlorinator. If the hypochlorinator is set at a pumping rate of 65 GPD and uses a 2.5 percent available chlorine solution, what is the chlorine dose rate in mg/*L*? The water pump delivers 400 GPM.
    1. 1.6 mg/*L*
    2. 2.4 mg/*L*
    3. 2.8 mg/*L*
    4. 3.1 mg/*L*
    5. 3.2 mg/*L*

31. A ten-inch water main 450 feet long needs to be disinfected. An initial chlorine dose of 400 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the three-hour disinfection period. How many gallons of 5.25 percent sodium hypochlorite solution will be needed?
    1. 3.4 gallons
    2. 5.7 gallons
    3. 10.7 gallons
    4. 13.4 gallons
    5. 14.0 gallons

32. How many gallons of 15 percent sodium hypochlorite solution will be needed to disinfect a reservoir 30 feet in diameter and 6-feet deep? An initial chlorine dose of 80 mg/*L* is expected to maintain a chlorine residual of over 50 mg/*L* during the 24-hour disinfection period.
    1. 9.1 gallons
    2. 13.7 gallons
    3. 15.2 gallons
    4. 16.9 gallons
    5. 18.8 gallons

33. Estimate the gallons of hypochlorite pumped by a hypochlorinator if the hypochlorite solution is in a container with a diameter of 30 inches and the hypochlorite level drops 26 inches during a specific time period.
    1. 69 gallons
    2. 80 gallons
    3. 86 gallons
    4. 88 gallons
    5. 95 gallons

34. Estimate the desired strength (as a percent chlorine) of a hypochlorite solution being pumped by a hypochlorinator that delivers 60 gallons per day. The water being treated requires a chlorine feed rate of 15 pounds of chlorine per day.
    1. 3.0%
    2. 3.3%
    3. 8.0%
    4. 9.0%
    5. 9.9%

End of Objective Test

CHAPTER 6

SAFETY

by

Dan Saenz

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OBJECTIVES

Chapter 6. SAFETY

Following completion of Chapter 6, you should be able to:

1. *THINK SAFETY,*
2. Develop a safety program for a water utility agency,
3. Prepare and conduct tailgate safety sessions,
4. Safely operate and maintain pumps and wells, with attention to the safety of operators and consumers,
5. Work safely in streets,
6. Protect the motoring public and pedestrians from work areas in streets and sidewalks, and
7. Conduct a safety inspection of waterworks facilities.

GLOSSARY

Chapter 6. SAFETY

ACUTE

ACUTE

Effects of an exposure which causes severe symptoms to occur quickly.

CHRONIC

CHRONIC

Effects of an exposure which causes symptoms to continue for a long time.

CONFINED SPACE*

CONFINED SPACE

A space defined by the concurrent existence of the following conditions:

A. Existing ventilation is insufficient to remove dangerous air contamination and/or oxygen deficiency which may exist or develop, and

B. Ready access or egress (getting out) for the removal of a suddenly disabled employee (operator) is difficult due to the location and/or size of the opening(s).

Also see definitions of *DANGEROUS AIR CONTAMINATION* and *OXYGEN DEFICIENCY*.

DANGEROUS AIR CONTAMINATION

DANGEROUS AIR CONTAMINATION

An atmosphere presenting a threat of causing death, injury, acute illness, or disablement due to the presence of flammable and/or explosive, toxic or otherwise injurious or incapacitating substances.

A. Dangerous air contamination due to the flammability of a gas or vapor is defined as an atmosphere containing the gas or vapor at a concentration greater than 20 percent of its lower explosive (lower flammable) limit.

B. Dangerous air contamination due to a combustible particulate is defined as a concentration greater than 20 percent of the minimum explosive concentration of the particulate.

C. Dangerous air contamination due to the toxicity of a substance is defined as the atmospheric concentration immediately hazardous to life or health.

MATERIAL SAFETY DATA SHEET (MSDS)

MATERIAL SAFETY DATA SHEET (MSDS)

A document which provides pertinent information and a profile of a particular hazardous substance or mixture. An MSDS is normally developed by the manufacturer or formulator of the hazardous substance or mixture. The MSDS is required to be made available to employers and operators whenever there is the likelihood of the hazardous substance or mixture being introduced into a workplace.

OXYGEN DEFICIENCY

OXYGEN DEFICIENCY

An atmosphere containing oxygen at a concentration of less than 19.5 percent by volume.

TAILGATE SAFETY MEETING

TAILGATE SAFETY MEETING

The term *TAILGATE* comes from the safety meetings regularly held by the construction industry around the tailgate of a truck.

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* *CONFINED SPACES, General Industry Safety Orders, Article 108, Title 8, California Administrative Code, Cal/OSHA Consultation Service, Sacramento, California, October 1980.*

CHAPTER 6. SAFETY[1]

(Lesson 1 of 2 Lessons)

6.0 IMPORTANCE OF SAFETY

6.00 Think Safety

LET'S START THINKING SAFETY NOW! In this section we are going to provide you with some ideas for your safety program. The remaining sections of this chapter will discuss how to perform specific jobs safely. Two very important aspects of your safety program are:

1. Making people aware of unsafe acts, and
2. Conducting and/or participating in regular safety training programs.

6.01 What is Safety?

Webster states that safety is the following:

> "The condition of being safe; freedom from exposure to danger; exemption from hurt, injury or loss; to protect against failure, breakage or other accidents; knowledge of or skill in methods of avoiding accident or disease."

Safety is more than words. Safety is the action of Webster's definition. Safety is using one's knowledge or skill to avoid accidents or to protect one's self and others from accidents. Safety is a form of preventive maintenance which includes equipment and machinery and its proper handling. Who is responsible for safety? Everyone should be responsible from top management to all employees.

Safety is a program for everybody, not only on the job but also at home. Unfortunately, people miss more time at work from off-the-job accidents than from on-the-job accidents!

Management has its responsibilities for safety; its main function is to set the tone and provide the training and monies for an effective safety program. Management should be responsible for the following:

1. Establish a safety policy;
2. Assign responsibility for accident prevention, which includes description of the duties and responsibilities of a safety officer, department heads, line supervisors, safety committees and operators;
3. Appoint a safety officer or coordinator;
4. Establish realistic goals and periodically revise them to insure continuous and maximum effort; and
5. Evaluate the results of the program.

While management has its responsibilities, the operators also have their particular responsibilities. Operators should:

1. Perform their jobs in accordance with established safe procedures,
2. Recognize the responsibility for their own safety and that of fellow operators,
3. Report all injuries,
4. Report all observed hazards, and
5. Actively participate in the safety program.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 330.

6.0A List two very important aspects of a safety program.

6.0B What are management's responsibilities for safety?

6.0C What are the operator's responsibilities for safety?

6.1 SAFETY PROGRAM

6.10 Objective of Safety Program

A SAFETY PROGRAM HAS ONE OBJECTIVE: TO PREVENT ACCIDENTS. Accidents do not happen, they are caused They may be caused by unsafe acts of operators or result from hazardous conditions or may be a combination of both. An analysis of accident statistics reveals that operator negligence and carelessness are the causes of most accidents. We know how to do our job safely, but we just don't do it safely.

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[1] *Portions of this chapter include safety material developed and distributed by the Department of Water and Power, City of Los Angeles.*

Accidents reduce efficiency and effectiveness. An accident is that occurrence in a sequence of events that usually produces unintended injury, death or property damage. Accidents affect the lives and morale of operators. They raise the costs not only to management but also to operators.

6.11 Unsafe Acts

Safety authorities tell us that nine out of ten injuries are the result of unsafe acts of either the person injured or someone else. Here are some of the principal reasons for unsafe acts.

•*IGNORANCE.* This may be due to lack of experience or training, or to a temporary condition that prevents the recognition of a hazard.

•*INDIFFERENCE.* Some know better but don't care. They take unnecessary risks and disregard the rules or instructions.

•*POOR WORK HABITS.* Some people either don't learn the right way of doing things, or they develop a wrong way. Supervisors or fellow operators who see things done unsafely must speak up.

•*LAZINESS.* Laziness affects speed and quality of work. Laziness also affects safety, because safety requires an effort. In most jobs you cannot reduce your "safety effort" and still maintain the same level of safety, even if you slow down or lower your quality standards.

•*HASTE.* When we rush, we work too fast to think about what we are doing; we take dangerous shortcuts, and we are more likely to be injured.

•*POOR PHYSICAL CONDITION.* Some of us just won't take reasonable care of ourselves. We ignore our bodily needs in regard to exercise, rest and diet, lessening our endurance and alertness.

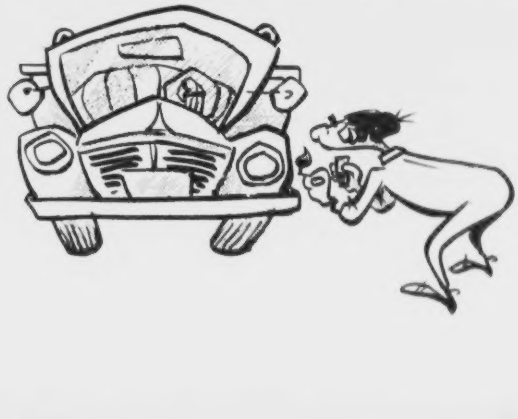
•*TEMPER.* Impatience and anger cause many accidents. Again, our thinking is interfered with and the way prepared for an accident.

Therefore, every one of these unsafe acts could be considered due to operator negligence or carelessness.

SAFETY QUOTE: THE MORE YOU TALK ABOUT SAFETY, THE LESS YOU HEAR ABOUT ACCIDENTS.

6.12 Driving Safety

Defensive drivers are safe drivers. Good drivers check and maintain vehicles properly, use the safety equipment, are courteous to other drivers, use proper signals in advance of any directional changes, and know and observe all traffic regulations. Defensive drivers always use seat safety belts and make sure that all lights — headlights, tail lights and directional lights — are operating correctly. Good drivers check to see that the tires are inflated to the proper pressure and that there are no bald spots or that the tires are not wearing unevenly. Brakes should be operating correctly. They should be able to stop your vehicle without grabbing or pulling to one side. Routine oil changes, observation of adequate coolant levels and tune ups should be performed periodically. The vehicle should be operated following the manufacturer's recommendations, observing your water utility's safe driving policies and observing all state and local driving regulations.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 330.

6.1A What is an accident?

6.1B How can you determine if the brakes on a vehicle are working properly?

6.1C List the principal reasons for unsafe acts.

6.1D What problems are caused by laziness?

6.13 Towing a Trailer

Frequently it is necessary to tow trailer-mounted equipment such as generators, compressors, and pumps. Towing a trailer requires experience, knowledge and a great amount of common sense. The job of towing a trailer seems to be a simple task; however, there are many pitfalls if good judgment is not exercised, or if the safety of others is not considered.

Many accidents related to trailer towing occur while simply coupling the trailer to the vehicle. Back strains and cuts and bruises to the hands and fingers are the injuries occurring before starting to tow a trailer.

The trailer and towing vehicle should be inspected and checked for the following:

1. Rear, turn signal, and brake lights,
2. Tire tread and inflation,
3. Wheel attachment (vandals may have loosened lug nuts),
4. Trailer brake operation if equipped with brakes,
5. Trailer hitch and tongue, and
6. Safety chain. After the trailer is coupled, the safety chain should be securely attached to the frame of the towing vehicle with enough slack to allow jack-knifing, but not enough to drag on the ground.

Once underway with a trailer in tow, the three items below are examples of when good judgment should be exercised:

1. Maximum speed for all vehicles is 55 mph — Remember that some trailers will not handle properly even at 45 mph.
2. Braking or stopping distances will increase if the trailer itself is not equipped with brakes.
3. Trailers make your vehicle much longer. Allow extra room when making turns, changing lanes or passing.

6.14 How to Charge a Battery

At one time or another you may have given a battery a boost or may have seen it done. There is a correct procedure to follow to eliminate damage to electrical components and to prevent a battery explosion (Figure 6.1).

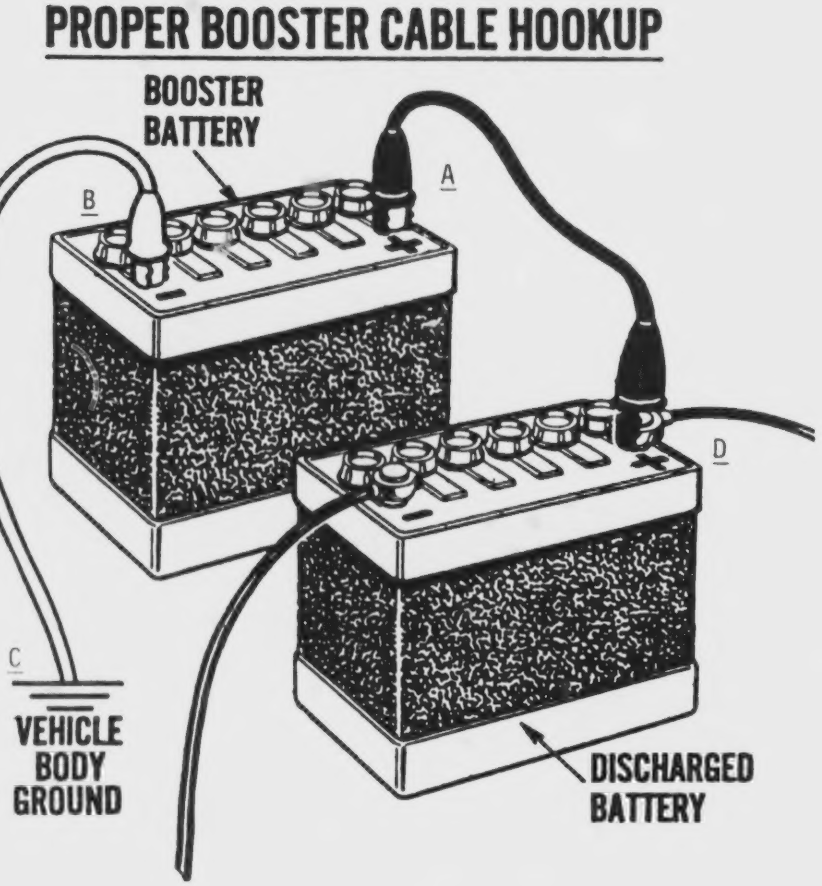


Fig. 6.1 Proper booster cable hookup

To boost the battery of a disabled vehicle from that of another vehicle, follow this procedure. First put out all cigarettes and flames. A spark can ignite hydrogen gas from the battery fluid. Next take off the battery caps, if removable, and add distilled water if it is needed. Check for ice in the battery fluid. Never jump-start a frozen battery! Replace the caps.

Next, park the auto with the "live" battery close enough so the cables will reach between the batteries of the two autos. The cars can be parked close, but do not allow them to touch. If they touch, this can create a dangerous situation. Now set each car's parking brake. Be sure that an automatic tranmission is set in park, put a manual-shift transmission in neutral. Make sure your headlights, heater, and all other electrical accessories are off (you don't want to sap electricity away from your dead battery while you are trying to start your car). If the two batteries have vent caps, remove them. Then lay a cloth over the open holes. This will reduce the risk of explosion (relieves pressure within the battery).

Attach one end of the jumper cable to the positive terminal of the booster battery (A) (that's the good battery in the other car) and the other end to the positive terminal of your battery (D). The positive terminal is identified by a + sign, a red color, or a "P" on the battery in your car. Each of the two booster cables has an alligator clip at each end. To attach, you simply squeeze the clip, place it over the terminal, then let it shut. Now attach one end of the remaining booster cable to the negative terminal of the booster battery (B). The negative terminal is marked with a – sign, a black color, or the letter "N." Attach the other end of the cable to a metal part on the engine of your car (C). Many mechanics simply attach it to the negative post of the battery. This is not recommended because a resulting arc could ignite hydrogen gas present at the battery surface and cause an explosion. Be sure the cables do not interfere with the fan blades or belts. The engine in the other car should be running, although it is not an absolute necessity.

Get in the disabled car and start the engine in a normal manner. After it starts, remove the booster cables. Removal is the exact reverse of installation. Remove the black cable attached to your engine, then remove it from the negative terminal of the booster battery. Then remove the remaining cable from the positive terminal of the "dead" battery and from the fill-holes. Replace the vent caps and you are done. Have the battery and/or charging system of the car checked by a mechanic to correct any problems.

For maximum eye safety, everyone working with car batteries or standing nearby should wear protective goggles to keep flying battery fragments and chemicals out of the eyes.

Should battery acid get into the eyes, immediately flush them with water continuously for 15 minutes. Then see a doctor.

The recommended procedure for jump-starting is listed, step by step, on a 4 inch by 8 inch yellow vinyl sticker which has a permanent adhesive. The sticker can be affixed to any clean, dry surface under the hood or kept inside the car's glove compartment. Stickers are available — 25¢ for one sticker, 12¢ for each additional one up to 100, $10 per 100, $80 per 1,000 — by writing the National Society to Prevent Blindness, Dept. B, 79 Madison Avenue, New York, NY 10016.

6.15 Boat Safety

Boats are commonly used in the operation of a water utility. They are used for sampling, surveying or inspecting reservoirs. Boats may be either motor operated (inboard or outboard) or rowboats. All boats should be inspected annually. The U.S. Coast Guard is usually the inspecting agency. They also recommend the safety practices to be used for boat safety. All boats should be equipped with a safety vest for each occupant or some type of approved flotation cushion. There should be oar-locks for the oars and oars should be of a suitable length for the respective boat and maintained in good operable condition. No boat should be loaded in excess of its loading capacity.

Motorized boats should meet the same conditions as rowboats. In addition the motors (inboard and outboard) should be maintained in good operating condition. Periodic tune ups and safety checks should be made following your utility's maintenance procedures or the manufacturer's recommendations. All motorized boats should have a set of oars to be used in an emergency and a fire extinguisher. At least two people should go out on a boat. If it is necessary that only one person use a boat, someone on shore should be aware that the person is out on the boat alone. Following safety practices when using boats could save someone from a potential drowning accident.

6.16 Corrosive Chemicals

A corrosive chemical is any chemical which may weaken, burn and/or destroy a person's skin or eyes. A corrosive chemical may be either acid or base (alkali). The pH scale from 0 to 14 is an indication of the strength of a solution. The "acids" with the low pH values are the most corrosive. Hydrochloric (HCl), nitric (HNO_3), and sulfuric (H_2SO_4) are among the strongest acids. A "base" with the highest pH values of around 13 are the most corrosive. Sodium hydroxide (NaOH) is a strong base. Some common chemicals which are corrosive are:

1. Ammonium hydroxide,
2. Calcium hypochlorite,
3. Chlorine,
4. Ferric chloride,
5. Hydrochloric acid,
6. Potassium permanganate,
7. Sodium chlorite,
8. Sodium hydroxide,
9. Sodium hypochlorite,
10. Sodium nitrate,
11. Sulfuric acid, and
12. Zinc orthophosphate.

This list is by no means complete.

Safety procedures must be followed in the handling and usage of all corrosive chemicals. Use safety protection equipment to protect your eyes and skin (see Section 6.21, "Protective Clothing"). Safety showers and eye/face wash should be installed at a location close to where any corrosive chemical is being used. Test the shower and eye/face wash at least once a week. Run the water using the emergency levers (the pull chains, hand-actuated valves or treadle foot-actuated valves). Let the water run for approximately three to five minutes or until the water runs clear. Rust may be in the water lines and may increase the problem of washing chemicals from your eyes.

6.17 Tailgate Safety Sessions

Tailgate safety sessions are so called because the session consists of a small group of operators gathered around the tailgate of a pickup or truck to discuss safety. These sessions are usually held near the work site and new and old safety hazards and safer approaches or techniques to deal with the problems of the day or week are discussed. The amount or degree of organization or formality of the sessions depends on the types of safety problems and what you think is the most effective way of educating your crew. Table 6.1 is a typical topic for a tailgate safety session.

TABLE 6.1. TAILGATE SAFETY TOPIC

Most injuries that happen on water utility jobs are caused directly by the injured person. Only a small percent are caused by defective equipment or devices. Because of this, you must be primarily responsible for your own safety.

Management and supervision are usually regarded as being the ones responsible for safety. Without proper interest on the part of management and supervision, a total safety program can't be effective. But you must realize that you, more than anyone else, are responsible for not only your own safety but for the safety of your fellow operators. In other words, you must be your "brother's keeper."

Here's an example of what we're trying to say. Management can purchase new trucks and equip them with all the known safety devices and maintain them in perfect operating condition. But a truck has to be operated by a driver (you); you alone are responsible for its safe operation so that neither you nor any of your fellow operators will get hurt.

Here's another example. Take the simple wooden ladder. The ladder may be built to the best safety specifications; it may have been properly stored and frequently inspected for defects. Somebody, however, must place the ladder in position and somebody must use it. If it's not properly placed, if the footing is insecure, if it hasn't been secured to the building by some individual, it is entirely likely that the person using it or some other operator will get hurt. And how can either management or supervision be held responsible for such accidents? You must realize that you are the most vital factor in the control of accidents.

Some operators seem to think that the safety officer is responsible for preventing accidents. Even though the safety officer frequently makes inspections and counsels the operators and supervisors, the safety operator can't be in all places at all times. And the safety officer cannot, therefore, be blamed or held responsible whenever an accident occurs. So let's bear in mind that we ourselves, as individuals, must constantly be alert to the hazards around us. If we can't remove a hazard ourselves, we should call it to the attention of those who have the authority to do so.

6.18 Employee "Right-To-Know" Laws

Employee "Right-To-Know" legislation has been implemented to require employers to inform employees (operators) of the possible health effects resulting from contact with hazardous substances. At locations where this legislation is in force, employers must meet certain requirements. Employers must provide operators with information regarding any hazardous substances which the operators might be exposed to under either normal work conditions or reasonably foreseeable emergency conditions resulting from workplace conditions. Information regarding hazardous substances is available from manufacturers in the form of Material Safety Data Sheets (MSDS) for hazardous substances. Employers must provide operators with a copy of MSDSs upon request and also must train operators to work safely with the hazardous substances that are encountered in the workplace.

As an operator you have the right to ask your employer if you are working with any hazardous substances. If you work with any hazardous substances, your employer must provide you with information on the health implications resulting from contact with the substances, the Material Safety Data Sheets, and training for working safely with the hazardous substances.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 330.

6.1E List the items that should be inspected before towing a trailer.

6.1F Why should all cigarettes and flames be put out before attaching cables to charge a battery?

6.1G List the safety practices for using boats.

6.1H What is a corrosive chemical?

6.1I What is a tailgate safety session?

6.2 PERSONAL SAFETY

Personal safety goes hand-in-hand with a good, effective safety program. You are the key individual to an effective safety program.

Don't you, as an operator, become a statistic

Table 6.2 is a tabulation of the types of accidents encountered in the water utility field. This chapter will provide you with safe procedures which will help you avoid becoming an accident statistic.

TABLE 6.2 ANALYSIS OF ACCIDENT TYPES[a]

	Percent
1. Sprains/strains in lifting, pulling or pushing objects	28
2. Sprains/strains due to awkward position or sudden twist or slip	16
3. Struck by falling or flying objects	10
4. Struck against stationary or moving objects	9
5. Falls to different level from platform, ladder, stairs	7
6. Caught in, under or between objects	6
7. Falls on same level to working surface	5
8. Contact with radiations, caustics, toxic and noxious substances	3
9. Animal or insect bites	1
10. Contact with temperature extremes	1
11. Rubbed or abraded	1
12. Contact with electric current	0
13. Miscellaneous	11

[a] AWWA Safety Bulletin

6.20 Monitoring Equipment

There are many locations in a water utility where it is necessary to monitor the atmosphere before entering. Some of these specific locations may be underground regulator vaults, soluton vaults, manholes, tanks, trenches and other *CONFINED SPACES*[2] (also see Section 6.63, "Confined Spaces"). There are a variety of devices that are used to monitor (check) the available oxygen and also combustible and toxic gases. Regardless of what type of monitoring device or devices are used, you should always test for *DANGEROUS AIR CONTAMINATION*[3] and/or *OXYGEN DEFICIENCY*[4] with an approved device immediately prior to an operator entering a confined space and at intervals frequent enough to insure a safe atmosphere during the time an operator is in the structure. Dangerous air contamination includes explosive conditions and toxic gases. Toxic gases include hydrogen sulfide and carbon monoxide. *A RECORD OF THE TEST MUST BE KEPT AT THE JOB SITE* for the duration of the work. *YOUR LIFE* and that of *YOUR FELLOW OPERATORS* is in jeopardy if the air in a confined space is not tested before entering. The following four steps should be performed before entering a confined space:

1. *CALIBRATE* the gas detection device,
2. *BARELY OPEN* the confined space,
3. *TEST* for combustible and toxic gases and oxygen deficiency using a probe or tube to collect the sample,
4. *RECORD* the results of these tests in your gas log, and
5. *VENTILATE* the confined space.

If a hazardous atmospheric condition is discovered, you must repeat the tests for combustible and toxic gases and oxygen deficiency while ventilating and again *RECORD* the results.

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[2] *Confined Space.** *A space defined by the concurrent existence of the following conditions:*
  A. Existing ventilation is insufficient to remove dangerous air contamination and/or oxygen deficiency which may exist or develop, and
  B. Ready access or egress (getting out) for the removal of a suddenly disabled employee (operator) is difficult due to the location and/or size of the opening(s).

[3] *Dangerous Air Contamination. An atmosphere presenting a threat of causing death, injury, acute illness, or disablement due to the presence of flammable and/or explosive, toxic or otherwise injurious or incapacitating substances.*
  A. Dangerous air contamination due to the flammability of a gas or vapor is defined as an atmosphere containing the gas or vapor at a concentration greater than 20 percent of its lower explosive (lower flammable) limit.
  B. Dangerous air contamination due to a combustible particulate is defined as a concentration greater than 20 percent of the minimum explosive concentration of the particulate.
  C. Dangerous air contamination due to the toxicity of a substance is defined as the atmospheric concentration immediately hazardous to life or health.

[4] *Oxygen Deficiency. An atmosphere containing oxygen at a concentration of less than 19.5 percent by volume.*

* *CONFINED SPACES, General Industrial Safety Orders, Article 108, Title 8, California Administrative Code, Cal/OSHA Consultation Service, Sacramento, California, October 1980.*

On rare occasions, unusual conditions may exist or be created even though the required testing procedures have been followed. Air currents through duct lines can easily change if other vaults in the same system are opened. Toxic or explosive gases from broken gas lines or decayed vegetation may then flow through the ducts into a previously gas-free vault. Therefore it is important that *ADEQUATE VENTILATION BE MAINTAINED AND THAT THE SPACE BE RECHECKED FOR HAZARDOUS ATMOSPHERES PERIODICALLY WHILE OPERATORS ARE WORKING IN SUCH LOCATIONS.* Use portable fans or ventilators to provide fresh air.

At least one person must stay outside the confined work area. This standby person should check continuously on the status of personnel working in the confined space. Should a person working in the confined space be rendered unconscious due to asphyxiation or lack of oxygen, the standby at the surface could descend into the space by:

1. Securing a back up rescue person, and
2. Donning the correct type of respiratory protective equipment.

Self-contained breathing equipment should be nearby and used as necessary.

Follow the procedures outlined in the *SAFETY NOTICE* whenever anyone must enter a confined space.

SAFETY NOTICE

Before anyone ever enters a tank for any reason, these safety procedures must be followed:

1. Test atmosphere in the tank for toxic and explosive gases and for adequate oxygen. Contact your local safety equipment supplier for the proper types of atmospheric testing devices. These devices should have alarms which are activated whenever an unsafe atmosphere is encountered;
2. Provide adequate ventilation, especially when painting. A self-contained positive-pressure breathing apparatus may be necessary when painting;
3. All persons entering a tank must wear a safety harness, and
4. One person must be at the tank entrance and observing the actions of all people in the tank. An additional person must be readily available to help the person at the tank entrance with any rescue operation.

Table 6.3 lists some common dangerous gases which may be encountered by the operators of water supply systems and water treatment plants.

The "proper" mixture of oxygen with a gas is necessary to create explosive or flammable conditions. If there is not enough gas present (too much oxygen), the mixture is too lean and will not burn or explode. Also, if there is too much gas (not enough oxygen), the mixture is too rich and will not burn or explode. The range of explosive or flammable gas mixtures is defined by the Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL). The objective of gas detection equipment is to warn us when we encounter explosive conditions within 20 percent of the Lower Explosive Limit. Anytime a gas mixture is within 20 percent of the Lower Explosive Limit, this is considered a hazardous condition.

Figure 6.2 shows the relationship between the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL) of a mixture of air and gas. Note in Table 6.3 that the percent by volume of a gas in air for the Lower Explosive Limit to occur is different for each gas. Also note in Figure 6.2 that if you have all gas (100% gas and 0% oxygen), the mixture is too rich and will not explode. If a mixture og gas and oxygen from the air is greater than 20 percent of the Lower Explosive Limit, the mixture is considered hazardous.

Monitoring equipment is essential to protect you from hazardous atmospheres when entering and working in enclosed spaces. This type of monitoring equipment is available in three different types;

1. Portable and attached to your clothing or your body,
2. Portable and carried by you or placed near your work site, and
3. Permanently installed in locations where hazardous atmospheres could develop.

You may encounter three types of hazardous atmospheres:

1. Toxic gases such as chlorine, carbon monoxide or hydrogen sulfide,
2. Explosive or flammable conditions, and
3. Oxygen deficiency.

Regardless of the type of detection devices that you are using to monitor hazardous atmospheres, regularly calibrate the detection devices according to manufacturer's recommendations. These calibration procedures must be scheduled and performed as part of your preventive maintenance program. Remember, the detection devices are sensitive instruments. Handle them gently and keep them accurate if you wish to stay alive.

The recommended warning devices should be an audible noise and/or a flashing light that should start whenever a hazardous condition is detected. An operator should not be expected to read a meter while working and decide whether or not a hazard exists.

Sometimes operators working in small communities or for small agencies experience problems convincing their supervisors of the need for gas detection devices, portable ventilators, safety harnesses, and qualified people standing by when they must enter tanks, vaults and manholes. OSHA regulations allow operators to refuse to perform work under unsafe conditions. This is a very difficult situation. We recommend that operators contact their local or state OSHA

TABLE 6.3 COMMON DANGEROUS GASES ENCOUNTERED IN WATER SUPPLY SYSTEMS AND AT WATER TREATMENT PLANTS

Name of Gas	Chemical Formulae	Specific Gravity of Vapor Density** (Air = 1)	Explosive Range (% by volume in air)		Common Properties (Percentages below are per cent in air by volume)	Physiological Effects (Percentages below are per cent in air by volume)	Most Common Sources in Sewers	Simplest and Cheapest Safe Method of Testing †
			Lower Limit	Upper Limit				
Oxygen (In Air)	O_2	1.11	Not flammable		Colorless, odorless, tasteless, nonpoisonous gas. Supports combustion.	Normal air contains 20.93% of O_2. Man tolerates down to 12%^{x}. Below 5 to 7% likely to be fatal.	Oxygen depletion from poor ventilation and absorption or chemical consumption of available O_2.	Oxygen deficiency indicator
Gasoline Vapor	C_5H_{12} to C_9H_{20}	3.0 to 4.0	1.3	7.0	Colorless, odor noticeable in 0.03%. Flammable. Explosive.	Anesthetic effects when inhaled. 2.43% rapidly fatal. 1.1% to 2.2% dangerous for even short exposure.	Leaking storage tanks, discharges from garages, and commercial or home dry-cleaning operations.	1. Combustible gas indicator. 2. Oxygen deficiency indicator for concentrations over 30%.
Carbon Monoxide	CO	0.97	12.5	74.2	Colorless, odorless, non-irritating, tasteless, Flammable. Explosive.	Hemoglobin of blood has strong affinity for gas causing oxygen starvation. 0.2 to 0.25% causes unconsciousness in 30 minutes.	Manufactured fuel gas.	CO ampoules.
Hydrogen	H_2	0.07	4.0	74.2	Colorless, odorless, tasteless, nonpoisonous, flammable. Explosive. Propagates flame rapidly; very dangerous.	Acts mechanically to deprive tissues of oxygen. Does not support life. A simple asphyxiant.	Manufactured fuel gas.	Combustible gas indicator.
Methane	CH_4	0.55	5.0	15.0	Colorless, tasteless, odorless, nonpoisonous. Flammable. Explosive.	See hydrogen.	Natural gas, marsh gas, mfg. fuel gas, sewer gas.	1. Combustible gas indicator. 2. Oxygen deficiency indicator.
Hydrogen Sulfide	H_2S	1.19	4.3	46.0	Rotten egg odor in small concentrations but sense of smell rapidly impaired. Odor not evident at high concentrations. Colorless. Flammable. Explosive. Poisonous.	Death in few minutes at 0.2%. Paralyzes respiratory center.	Petroleum fumes, from blasting, sewer gas.	1. H_2S analyzer. 2. H_2S ampoules.
Carbon Dioxide	CO_2	1.53	Not flammable		Colorless, odorless, non-flammable. Not generally present in dangerous amounts unless there is already a deficiency of oxygen.	10% cannot be endured for more than a few minutes. Acts on nerves of respiration.	Issues from carbonaceous strata. Sewer gas.	Oxygen deficiency indicator.
Nitrogen	N_2	0.97	Not flammable		Colorless, tasteless, odorless. Nonflammable. Nonpoisonous. Principal constituent of air (about 79%).	See hydrogen.	Issues from some rock strata. Sewer gas.	Oxygen deficiency indicator.
Ethane	C_2H_6	1.05	3.1	15.0	Colorless, tasteless, odorless, nonpoisonous. Flammable. Explosive.	See hydrogen.	Natural gas.	Combustible gas indicator.
Chlorine	Cl_2	2.5	Not flammable Not explosive		Greenish yellow gas, or amber color liquid under pressure. Highly irritating and penetrating odor. Highly corrosive in presence of moisture.	Respiratory irritant, irritating to eyes and mucous membranes. 30 ppm causes coughing. 40-60 ppm dangerous in 30 minutes. 1000 ppm apt to be fatal in few breaths.	Leaking pipe connections. Overdosage.	Chlorine detector. Odor, strong. Ammonia on swab gives off white fumes.

** Gases with a specific gravity less than 1.0 are lighter than air; those more than 1.0 heavier than air.

† The first method given is the preferable testing procedure.

^{x} Never enter a 12% atmosphere. Use detection meters with alarm warning devices rather than meters.

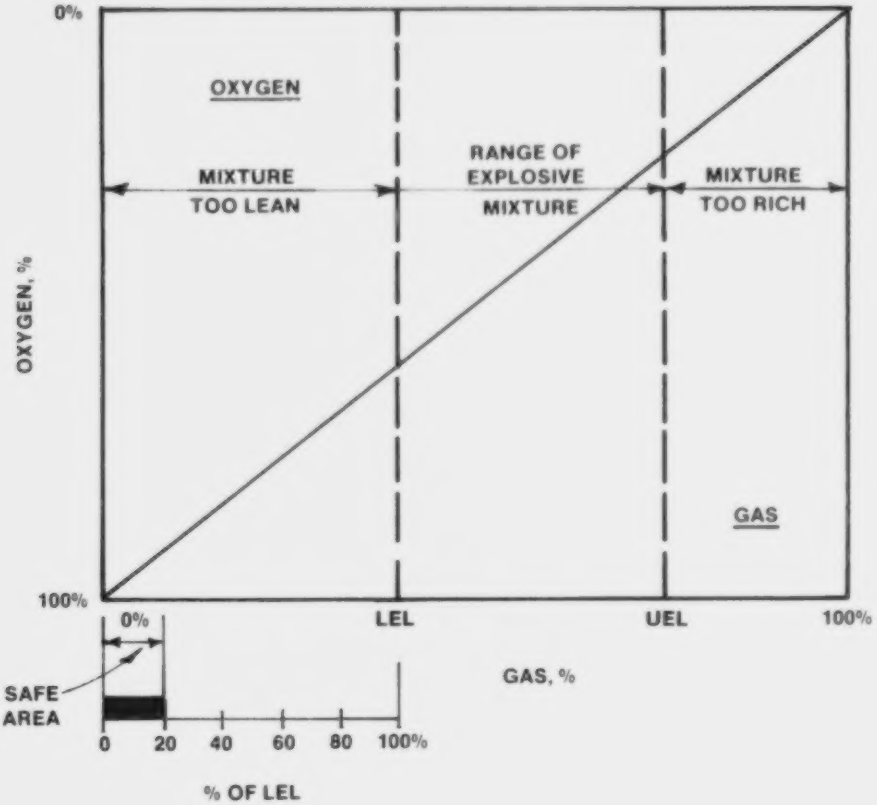

Fig. 6.2 Relationship between Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL)

officials or other industrial safety officials. Obtain copies of the rules and regulations for entering tanks and confined spaces (see Section 6.63, "Confined Spaces"). These regulations usually specify the conditions which must be monitored. More important, however, is that these regulations will specify the penalties imposed on supervisors and employers for failing to provide operators with the proper safety equipment, procedures and training. These penalties include stiff fines and jail sentences. Responsible employers and supervisors would rather comply with safety regulations than pay fines and spend time in jail.

OPERATORS HAVE THE RIGHT TO REFUSE TO DO ANYTHING THAT ENDANGERS THEIR LIVES.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 330.

6.2A List the typical locations in a water utility where it is necessary to monitor the atmosphere before entering.

6.2B Why should a standby person stand outside the confined work area?

6.2C At what level is a mixture of air and gas considered hazardous?

6.21 Protective Clothing (Figure 6.3)

Protective clothing is required for the protection of operators. Some clothing may be the responsibility of each operator and other protective equipment may be supplied by the water utility. Typical protective equipment supplied by the operators may be:

1. Safety toe (hard toe) shoes, and
2. Safety prescription glasses.

Protective equipment which may be required or supplied includes:

1. Safety (hard) hats,
2. Ear plugs,
3. Safety glasses (non-prescription),
4. Safety goggles,
5. Face shields,
6. Respirators and masks,
7. Canvas gloves,
8. Rubber gloves for use with corrosive chemicals,
9. Safety aprons,
10. Leggings/knee pads/safety belts or harnesses,
11. Safety toe caps, and
12. Protective clothing (lab coats or rubber suits).

Protective clothing must be worn and equipment used (as appropriate) whenever *YOU* are exposed to safety hazards as you do your job.

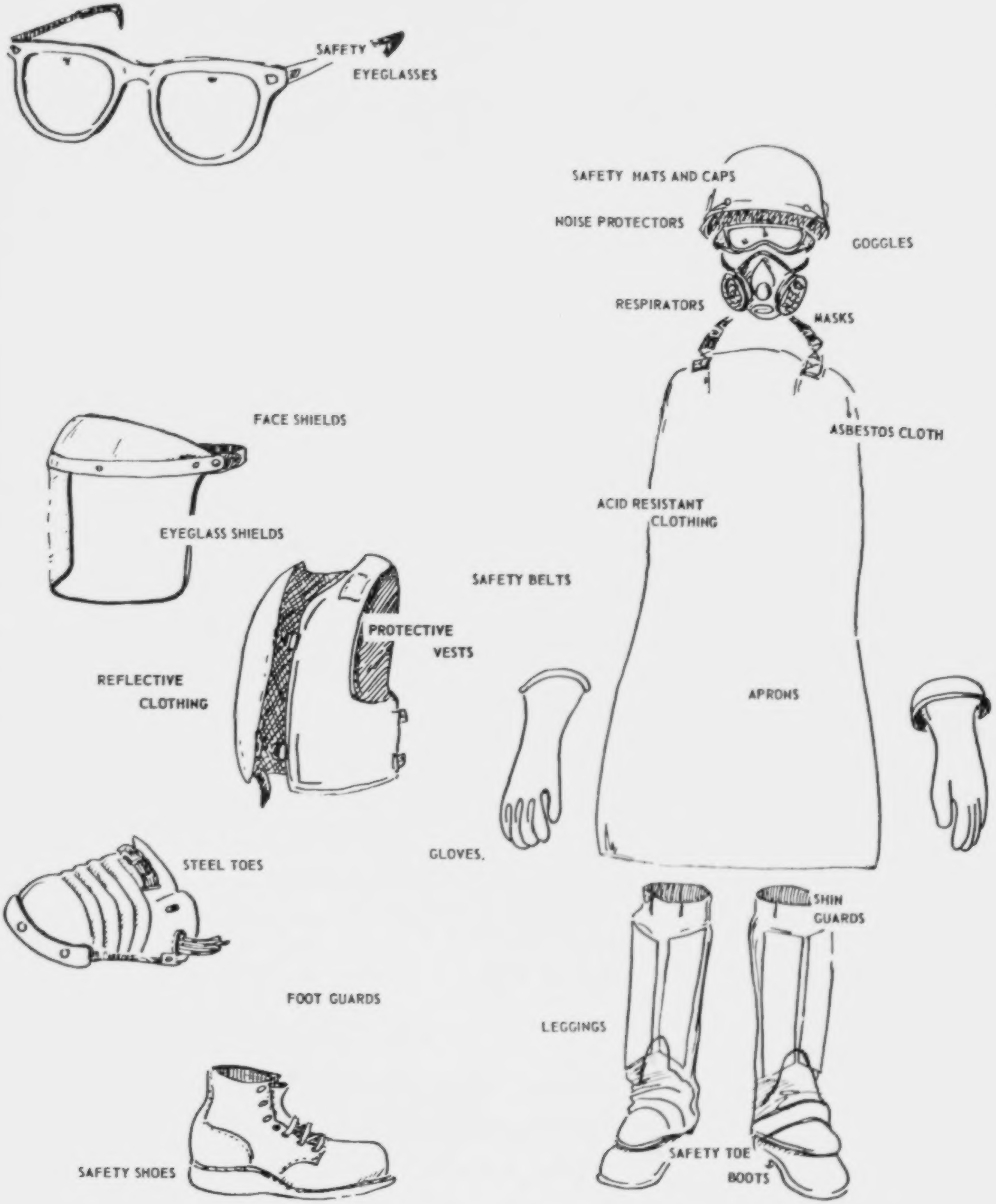
SAFETY EYEGLASSES
SAFETY HATS AND CAPS
NOISE PROTECTORS
GOGGLES
RESPIRATORS
MASKS
FACE SHIELDS
ASBESTOS CLOTH
ACID RESISTANT CLOTHING
EYEGLASS SHIELDS
SAFETY BELTS
PROTECTIVE VESTS
REFLECTIVE CLOTHING
APRONS
STEEL TOES
GLOVES.
SHIN GUARDS
FOOT GUARDS
LEGGINGS
SAFETY TOE BOOTS
SAFETY SHOES

Fig. 6.3 Protect all of you

6.22 Slips and Falls

Slips and falls are common accidents which can be a major problem in a water utility. All floors should be level and kept as slip resistant as possible. Floors should be free of all debris. Material that drips or spills can be collected in drip pans, appropriate gutters, or splash guards may be used to deflect drips. If liquids do get on floors, nonflammable absorbent materials should be available for cleaning up.

CAUTION: Sawdust should never be used as an absorbent because it is combustible.

When cracks, splinters, ruts or breaks occur in floors they should be repaired as soon as possible. Good housekeeping and maintenance go hand in hand to prevent slips and falls. If water and chemicals spill on the floor, they should be wiped up as soon as possible. Catwalks or safety tread may be necessary on floors where water or chemicals are commonly spilled. The catwalk or safety tread will help prevent unnecessary slips and falls.

All stairways and elevated catwalks should have safety railings. Approved caution signs should be used where necessary to call attention to potential hazards or remind operators to use caution or to use safety equipment.

SAFETY QUOTE: Falls cause more accidents than summers, winters or springs.

6.23 Handling and Lifting

Injuries caused by handling and lifting are many and varied. Approximately 28 percent of operator injuries can be directly attributed to the handling of objects. A large portion of strains and sprains, fractures and bruises, back injuries and hernias are the result of common handling injuries. These injuries are caused primarily by unsafe work practices such as:

1. Improper lifting,
2. Carrying too heavy a load,
3. Incorrect gripping,
4. Failing to observe proper foot or hand clearance, and
5. Failing to use or wear proper equipment.

Many of us do not think much of lifting but if we are lifting an object incorrectly, we may suffer bad results such as pulled muscles, disc lesions or painful hernias. Remember Figure 10.4 whenever you have a lifting job.

Here are seven steps to safe lifting:

1. Keep feet parted — one along the side of and one behind the object,
2. Keep back straight — nearly vertical,
3. Tuck your chin in,
4. Grip the object with the whole hand,
5. Tuck elbows and arms in,
6. Keep body weight directly over feet, and
7. Lift slowly.

Safety equipment should be used to help protect your body. To protect your hands, use the gloves; and your feet, safety shoes, instep protectors, and ankle guards. Size the weight of objects you must lift. Never lift more than you can safely carry. Use handles or holders that attach to the objects such as handles for moving auto batteries or baskets for carrying laboratory samples. If the object to be moved is awkward or too large or heavy for one operator, have two operators move the object in question. When more than one operator is used, the object to be lifted must be lifted in unison (all at once) and everyone must know how the object is to be lifted and handled. Only one operator is assigned the task of giving orders as necessary such as when to start, lift, carry and set down the object. All parties concerned should lift correctly with the legs bearing the bulk of the physical effort.

If the object to be lifted and handled is too heavy for a person or persons to move safely, then use hand trucks, dollies, or powered hand trucks to move and/or lift objects.

Remember, 28 percent of injuries are caused by improper lifting and handling. Your health and safety depends on you using correct lifting and handling procedures.

6.24 Electrical

Electrical safety is very important to your life. Whenever you must work on electrical equipment or equipment that is run by electric motors, be sure to lock out and tag all of the electrical switches. Only you should ever be allowed to remove a lockout device and tag that you have installed. Also you should never remove a tag or lockout device installed by another operator.

Water is a good conductor of electricity. Do not stand in water when working on electrical equipment.

Throughout this manual we have outlined safe procedures to follow whenever you must operate or maintain electrical equipment or equipment run by electrical motors.

Many water supply and water treatment monitoring, measuring and control systems are electrical. Always be very careful when working around or troubleshooting these instrumentation systems.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 330.

6.2D List as many items of protective clothing for operators as you can recall.

6.2E How can liquids spilled on floors be cleaned up?

6.2F List the steps to safe lifting.

6.2G What precautions should be taken when working on electrical motors?

6.3 SAFETY AROUND WELLS

6.30 Importance of Well Safety

Safety around wells is important for two reasons:

1. Safety control around the well site is necessary to prevent contamination or pollution of the well which could affect the health and safety of the consumer, and
2. Safety housekeeping of the site will help prevent an accident to operators or employees working near or around the well.

The well operator has the responsibility to preserve the quality of the well through preventive maintenance of the area where the well is located.

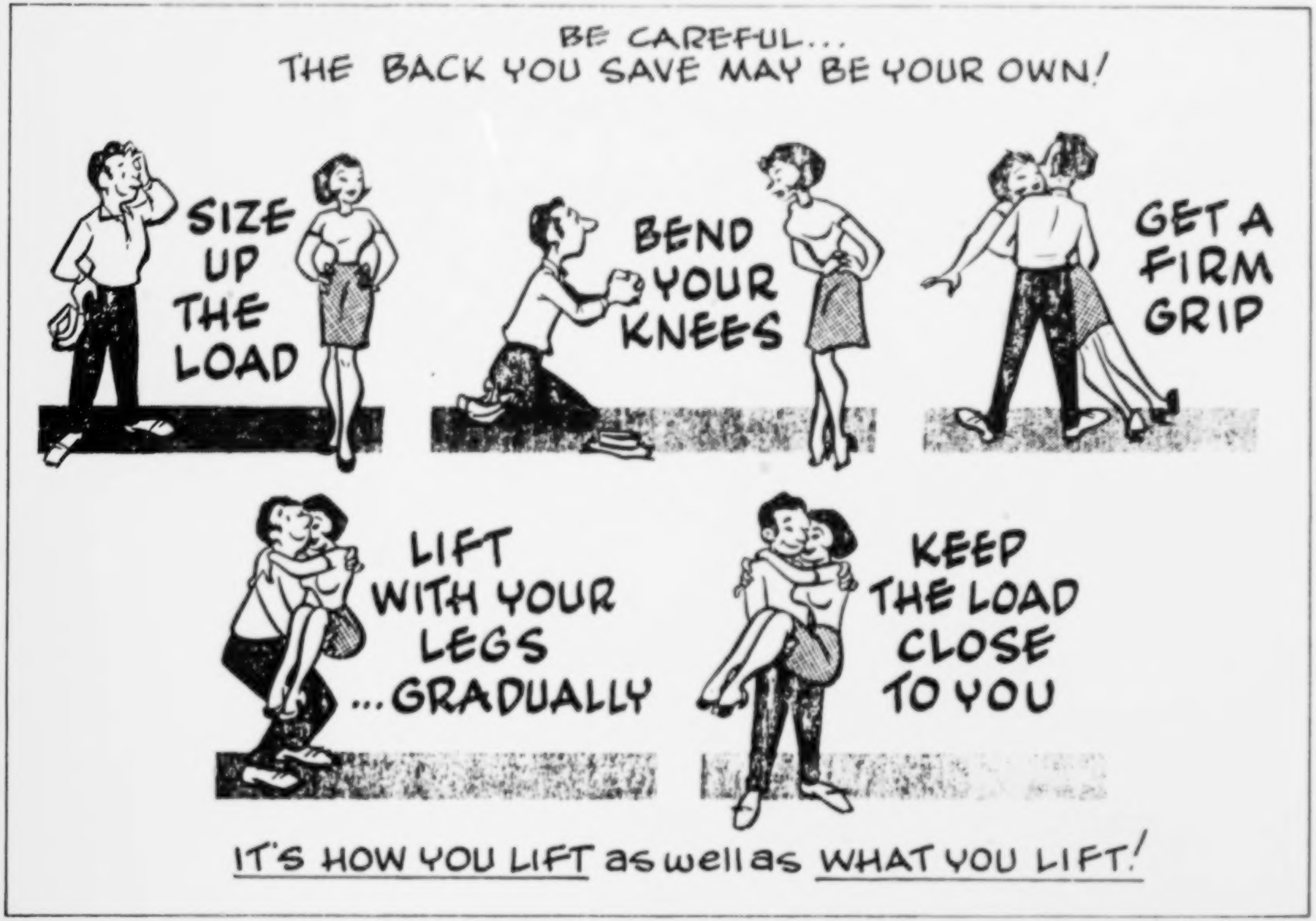
BE CAREFUL...
THE BACK YOU SAVE MAY BE YOUR OWN!
SIZE UP THE LOAD
BEND YOUR KNEES
GET A FIRM GRIP
LIFT WITH YOUR LEGS ...GRADUALLY
KEEP THE LOAD CLOSE TO YOU
IT'S HOW YOU LIFT as well as WHAT YOU LIFT!

Fig. 6.4 Lifting

(Reproduced from *OPERATION OF WASTEWATER TREATMENT PLANTS*, published by Foundation of California State University, Sacramento)

6.31 Location of Well Site

Selection of a well site requires serious consideration of several factors. The well should be located a suitable distance from any potential pollution source which may affect the groundwater. Some potential sources of pollution may be septic tanks, subsurface leaching systems, mining operations, solid and hazardous waste disposal sites and wastewater treatment facilities.

Some wells have been located in areas where initially the environment was correct for the site. The following are examples of well sites which were contaminated after a well had been in operation for some time.

EXAMPLE 1

A Girl Scout Camp leased a camp in the Angeles National Forest. This camp had two wells which supplied all the drinking water. The two wells were located in a small, narrow, secluded valley and for several years the bacteriological samples were negative. Camp officials decided to purchase horses to provide a special camping session where the camper could specialize in equestrian events. After a few years the well water bacteriological samples began to turn up positive. This water even had positive coliform samples with chlorination. After an investigation it was determined that the well was being contaminated because the horse stables were located above the well. During the rainy season the rain washed the horse manure down into the wells located below the stables.

EXAMPLE 2

A utility began to cut personnel because of fiscal problems. Some of the first cuts affected gardening personnel who cleaned up around the well site. After a few months the area around the well site became a dumping site. Old lumber, furniture, sofas, chairs, and garden clippings began to pile up around the well site. This debris attracted rodents; rats, ground squirrels and snakes close to the well site. This caused a potential problem to the employees and to the utility's consumers.

6.32 New Wells

No sewers should be permitted with 50 feet (15 m) of any well. If the well must be located within 100 feet (30 m) of a sanitary or storm sewer under gravity flow, special pipe and fittings must be used (see Chapter 3, "Wells," Section 3.15, "Well Site Selection").[5] This is necessary to prevent intrusion of leaking wastewater into the well.

6.33 Sanitary Seal

The sanitary seal on a well is the most important factor to prevent contamination of any type of well. This seal will prevent contaminated water or debris from entering around the well casing and into the water (review Chapter 3, "Wells," Section 3.14, "Well Structure and Components").

When applying disinfectant or using well cleaning agents, the operator must protect the well against the entrance of surface water or foreign matter.

6.34 Surface Portion of Well

All surface openings installed on top of a well must be protected against the entrance of surface water or foreign matter. Well casing vents should be constructed so that openings are in a vertical downward position. They should be a minimum of 36 inches (90 centimeters) in height above the finished surface of the well lot (ground surface) and should be covered with a fine mesh or device to exclude small insects from the inside of the well.

Gravel tubes must be capped at the top end, kept tightly sealed and elevated above ground level to prevent flood waters from entering the well.

The sounding tube must be kept tightly sealed. All pipe vents, sounding lines, and gravel fill pipes must be continuous conduit through the concrete pedestal. Also, all conduits which penetrate the casing must be provided with a continuous water tight weld at the point of entry into the well interior. A pump motor base seal must be water tight. All these safety requirements are necessary to insure that contaminants do not get into the well's interior. When these safety features are incorporated in a well's construction, the probability is lessened that the well will be contaminated by surface debris or waters. Review Chapter 3, "Wells," Section 3.1, "Surface Features of a Well."

6.35 Tank Coatings

Hydropneumatic pressure tanks incorporated with wells are normally painted on the interior surface with a protective coating to extend the life of the tank. Special consideration must be used in selecting the proper type of coating. The coating should be approved by the AWWA or the Additives Evaluation Branch of EPA and not be a cause of pollution or contamination of the drinking water. The application procedures are most important and the curing time is essential for proper results.

CAUTION

When applying a coating — personnel should use forced ventilation and/or a protective mask with an air line to provide an adequate air supply that is safe to work in. Coatings used in tanks are *VOLATILE* and can affect the respiratory system.

When applying coating, at least two operators should work together — one inside the tank and the other close by. The operator outside checks on the status of the person working inside and checks periodically on the forced ventilation system and air pressure for the air mask, if used. A third person must be readily available to assist the person outside with any rescue operations. See *SAFETY NOTICE*.

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[5] *Check with your local health department for distances which apply to your well.*

SAFETY NOTICE

Before anyone ever enters a tank for any reason, these safety procedures must be followed:

1. Test atmosphere in the tank for toxic and explosive gases and for adequate oxygen. Contact your local safety equipment supplier for the proper types of atmospheric testing devices. These devices should have alarms which are activated whenever an unsafe atmosphere is encountered;
2. Provide adequate ventilation, especially when painting. A self-contained positive-pressure breathing apparatus may be necessary when painting;
3. All persons entering a tank must wear a safety harness; and
4. One person must be at the tank entrance and observing the actions of all people in the tank. An additional person must be readily available to help the person at the tank entrance with any rescue operations.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

6.3A What are the safety responsibilities of the well operator?

6.3B How is contaminated water or debris kept from entering around the well casing and reaching the groundwater?

6.3C List the surface openings on top of a well that must be protected against the entrance of surface water or debris into the well.

6.36 Well Chemicals

6.360 Acid Cleaning

An acid treatment may be necessary to loosen incrustations from a well casing and well. Normally hydrochloric or sulfamic acids are used. Hydrochloric (HCl) acid should be used at full strength. Hydrochloric acid can be introduced into a well by means of a wide-mouthed funnel and a ¾- or 1-inch (16 or 25 mm) place pipe. Extend the place pipe into the well and attach the funnel to the end outside of the well. Pour the acid into the funnel and allow it to run into the well. If hydrochloric acid (muriatic acid — industrial name) is used, be careful! The pH of hydrochloric acid is approximately 1.0. This acid is very corrosive.

Inhalation of hydrochloric acid fumes can cause coughing, choking, and inflammation of the entire respiratory tract.

Swallowing even a small amount of this acid can cause corrosion of mucous membranes, esophagus and stomach; difficulty swallowing; nausea; vomiting; intense thirst; and diarrhea. Circulatory collapse and death may occur.

Hydrochloric acid causes severe skin burns. Spills, splashes or fumes may affect the eyes and could cause permanent eye damage.

Safety apparatus must be used when working with hydrochloric acid. Protective clothing includes rubber gloves, preferably long for hands — approximately 15 to 18 inches (38 to 45 cm), rubber apron for clothes protection, boots for foot protection in case of spillage, and face shield for protection against splashes and fumes.

Extreme care should be used in transporting acid. Acid should be carried in cases (gallons) or in carboys for protection and must be placed securely in a vehicle whenever transported.

Sulfamic acid has advantages over hydrochloric acid. Sulfamic acid may be used in granular form or as an acid solution mixed on site. Granular sulfamic acid is non-irritating to dry skin and its solution gives off no fumes except when reacting with incrusting materials. Spillage, therefore, presents no hazard and handling is easier, cheaper and safer.

Although sulfamic acid is non-irritating to dry skin and it gives off no fumes, rubber gloves should still be used because hands may become wet from perspiration and the acid will cause burns on the skin. Safety goggles or glasses, preferably a face shield, should be used in case granules are blown into the face and/or the eyes. If sulfamic acid is mixed on site, care should be used in mixing.

CAUTION

Acid should always be added slowly to the water. Use an acid-proof crock for mixing. Mix with a wooden paddle or electric mixer. Again, always use rubber gloves, rubber boots, a rubber apron and a face shield when mixing sulfamic acid.

NEVER ADD WATER TO ACID. ACID COULD SPLASH ALL OVER YOU.

When using any *CORROSIVE* or *CAUSTIC* chemical, an eye/face wash station must be available in case of an emergency. There are a variety of portable eye/face wash units commercially available. The unit should be located at a site which has easy access in case it is needed, preferably within 20 feet (6 m) of where the acid is being used. All personnel concerned should know the location of the eye/face wash station and be instructed on how to use it.

If anyone spills acid on their skin, the exposed area should be washed down with water as soon as possible. Also, they should change their clothes and shower if necessary. If acid is splashed on the face or in the eyes, immediately wash face/eyes with eye wash for at least 15 minutes. Make sure the eyes are thoroughly flushed with water. If irritation continues, resume washing eyes with water. Keep eyes moist with a wet towel and have a physician examine for further treatment.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

6.3D Why must hydrochloric acid be handled carefully?

6.3E What are the advantages of using sulfamic acid over hydrochloric acid to acid clean a well?

6.3F What safety precautions should be used when working with sulfamic acid in the granular form?

6.361 Chlorine Treatment

When a well requires treatment with chlorine, either granular calcium hypochlorite or liquid sodium hypochlorite is commonly used. Regardless of the type of hypochlorite used, safety equipment should be used. Again, use rubber gloves, preferably 15 to 18 inches (38 to 45 cm) long, a rubber apron, rubber boots and a face shield to protect against splashes. A portable eye/face wash should be available in case of splashes. Wear a "nursance mask" when working with granular or powdered chemicals because their dusts can be harmful.

Use caution in the transfer of hypochlorite compounds. They should be transferred in their original containers and handled with care. Operators must be trained in the use of calcium and sodium hypochlorite products. Follow manufacturers' recommendations or your utility's safety policy.

CAUTION

When using acid or chlorine products, be mindful of the dangerous potential that fumes may have. Therefore, whenever using an acid or a chlorine product, use them where there is adequate ventilation. If necessary, use a forced ventilation system in pump houses or confined spaces.

When working with chemicals around a well, keep all personnel out of pits or depressions around the well. During treatment some of the toxic gases, such as hydrogen sulfide, may rise from the well and settle in the lowest areas nearby because these gases are usually heavier than air.

6.362 Polyphosphate

Sodium polymetaphosphate is a chemical sometimes added to wells. This chemical may be sold commercially as Graham's salt, "Sodium hexametaphosphate," glassy sodium metaphosphate, or Hy-Phos $(NaPO_3)x$. The chemical is clear, hygroscopic (attracts moisture from the air), soluble in water, but it dissolves slowly in water. The chemical is supplied in the form of a powder, flake, or as small, broken glass-like particles which possess dispersing and deflocculating properties.

CAUTION

Glassy phosphate consists of broken glass particles which are very sharp and can cut your skin. Use heavy-duty gloves when handling. Respiration equipment or a face shield should be used.

An eye/face wash should be available if solution is splashed into the face or eyes. Wash face continuously for 15 minutes. Get medical attention.

6.363 Disinfection of Wells and Pumps

Care should be taken during the construction of new wells. All pipes used in the construction of a well should be as clean as possible. Regardless of how clean the pipe for the well casing is kept, a new well pump should be disinfected. This disinfection is necessary because contamination could be introduced into the well from the drilling tools and mud, make up water, topsoil falling into or sticking to tools, and from the gravel itself.

Disinfect a well or well pump with a chlorine solution strong enough to produce a chlorine concentration of 50 mg/*L* in the well casing. Use caution when disinfecting wells and pumps. Follow safety procedures listed under chlorine treatment in this chapter. Also refer to Chapter 3, Section 3.5, "Disinfection of Wells and Pumps."

6.37 Working Around Electrical Units

Electricity is supplied as an alternating current (A.C.) at 120, 240, or 480 volts. Most wells or large pumps will be energized by 240 or 480 volts. Extremely large pumps may be energized by even higher voltages. Place nonconducting rubber mats on the floor in front of all power panels and motor control centers.

Care and caution should be used when working around equipment that is hooked up to any electrical current.

When maintenance is to be done on wells or pumps, lock out the electrical current to the equipment. Open the breakers so that electrical current is turned off.[6] Place a tag (Figure 6.5) with your name on it on opened breakers and locks which indicates that you turned off the breakers and locks. No one should remove the tag or close the breakers or locks but you. This will allow the equipment to be pulled and worked on without the fear of being shocked or burned. Personnel working around high voltage equipment should be trained and have respect for electrical current.

After work is completed on the equipment, personnel should stand clear when the equipment is energized (electrical current turned on). Make sure that the equipment is properly grounded. Personnel working with electrical equipment should have a good knowledge of electrical circuits and circuit testing. They should get clearance (approval) to work on the equipment only if they are qualified. If no one is knowledgeable about electrical circuits, the water utility should contact an electrician from a local electrical firm.

Safe procedures that must be used when working around electrical equipment include:

1. Only qualified persons can work on electrical equipment,
2. Electrical installations must be maintained in a safe condition,

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[6] *When an electrician "closes" an electrical circuit, the circuit is connected together and electricity will flow. Closing a circuit is similar to opening a valve in a pipeline. The reverse is also true. Opening an electrical circuit is similar to closing a valve on a pipeline.*

DANGER

MAN WORKING ON LINE

DO NOT CLOSE THIS SWITCH WHILE THIS TAG IS DISPLAYED

SIGNATURE ______________________

This is the ONLY person authorized to remove this tag

NOTE: Tag also should include: TIME OFF ____________

DATE ____________

Fig. 6.5 Typical warning tag

(Source: Industrial Indemnity/Industrial Underwriters Insurance Cos.)

3. Electrical equipment and wiring must be protected from mechanical damage and environmental deterioration,
4. Covers or barriers must be installed on boxes, fittings and enclosures to prevent accidental contact with live parts,
5. An acceptable service pole must be used,
6. Equipment must be suitably grounded,
7. Provisions must be made for suitable overcurrent protection,
8. Machinery must be locked out during cleaning, servicing or adjusting,
9. Machinery must be de-energized, locked or blocked to prevent movement if exposed parts are dangerous to personnel, and
10. If a switch or circuit breaker is tagged and locked out, only the person placing the tag should remove it.

"REMEMBER:"
Leave electrical repairs to the experts.

6.38 Abandoning and Plugging of Wells

Wells that are no longer useful should be abandoned and plugged for the following reasons:

1. To assure that groundwater is protected and preserved for further use,
2. To eliminate the potential physical hazard to people, and
3. To protect nearby wells from contamination.

Obtain the appropriate permits from the proper agency. Depending on the locality, this may be a local, state or federal agency. Follow the guidelines issued by the permitting agency and use experts (such as a geologist) where necessary. Review Chapter 3, Section 3.18, "Abandoning and Plugging of Wells."

6.39 Safety Inspection

Safety around wells is the responsibility of the well operator. A periodic inspection should be performed at each well site whether the well is in service or out of service. Keep a record of each monthly inspection and use the remarks column to make special notations. Some things that you should inspect for are:

1. Cleanliness of site,
2. Locks on electrical panels,
3. Condition of fencing around site, and
4. Caution/warning signs in place where necessary.

Any problems or hazards, safety or otherwise, should be corrected as soon as possible. If you cannot take care of the problem, notify your supervisor about the nature of the problem and what type of support you will need to correct the problem.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

6.3G What protective clothing should be worn when handling hypochlorite?

6.3H How should glassy phosphate be handled?

6.3I If no one working for a water utility is knowledgeable about electrical circuits, how can a water utility have a malfunctioning electrical system repaired?

6.3J List the items that should be included in the safety inspection of a well site.

End of Lesson 1 of 2 Lessons
on
SAFETY

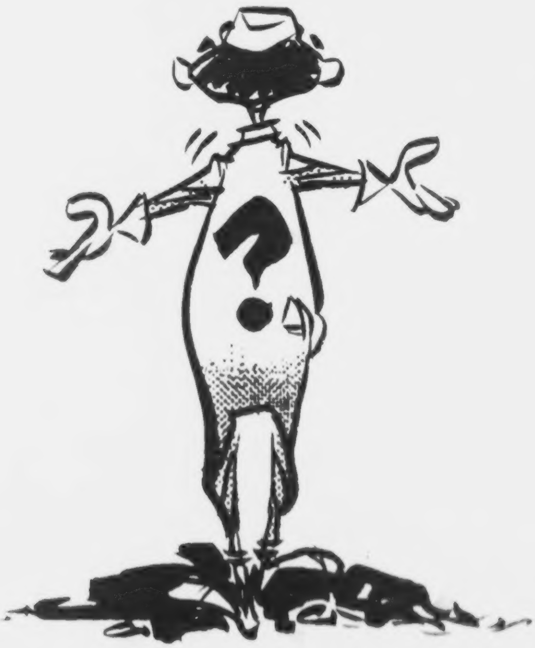
DISCUSSION AND REVIEW QUESTIONS

Chapter 6. SAFETY

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. What is safety?
2. Who is responsible for safety?
3. What is the one objective of a safety program?
4. What are the causes of accidents?
5. How would you test a safety shower and eye/face wash?
6. What should be done before entering a confined space?
7. Why should hazardous gas detection devices be calibrated regularly?
8. How can an object be moved if it is too heavy for operators to lift?
9. Why is safety around wells important?
10. How should hydrochloric acid be transported?
11. What would you do if acid splashed in your eyes?



CHAPTER 6. SAFETY

(Lesson 2 of 2 Lessons)

6.4 PUMP SAFETY

6.40 Uses of a Pump

When we think of pumps, we commonly think of pumping water. Actually, pumps can do many things as is illustrated by the following definitions of a pump:

1. An apparatus or machine which forces liquids, air, or gas into or out of things.
2. A machine which increases the static pressure of fluids (air and water).
3. Pumping is the addition of energy to a fluid which is used mainly for the purpose of moving the fluid from one point to another.

6.41 Guards Over Moving Parts

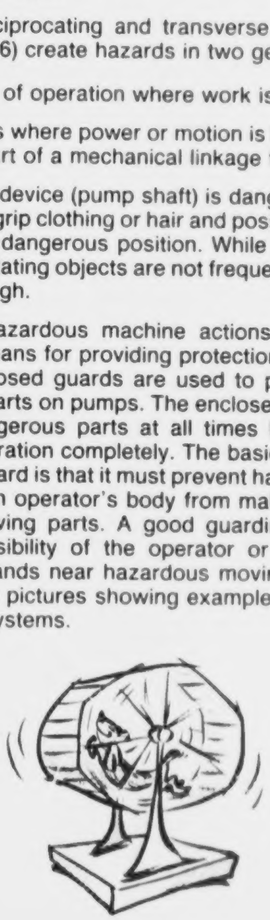
A pump has moving parts. Where there are moving parts there is potential danger. All mechanical action or motion is hazardous, but in varying degrees. *ROTATION MEMBERS, RECIPROCATING ARMS, MOVING PARTS,* and *MESHING GEARS* are some examples of action and motion requiring protection on pumps.

Rotating, reciprocating and transverse (crosswise) motions (Figure 6.6) create hazards in two general areas:

1. At the point of operation where work is done, and
2. At the points where power or motion is being transmitted from one part of a mechanical linkage to another.

Any rotating device (pump shaft) is dangerous. Whatever is rotating can grip clothing or hair and possibly force an arm or hand into a dangerous position. While accidents due to contact with rotating objects are not frequent, the severity of injury is very high.

Whenever hazardous machine actions or motions are identified, a means for providing protection for operators is essential. Enclosed guards are used to protect operators from rotating parts on pumps. The enclosed guard prevents access to dangerous parts at all times by enclosing the hazardous operation completely. The basic requirement for an enclosed guard is that it must prevent hands, arms or any other part of an operator's body from making contact with dangerous moving parts. A good guarding system eliminates the possibility of the operator or another worker placing their hands near hazardous moving parts. Figures 6.7 and 6.8 are pictures showing examples of good, effective guarding systems.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

6.4A What are the uses of pumps?

6.4B List the moving parts on a pump which require guards.

6.4C How can rotating devices injure you?

6.4D What is the basic requirement for an enclosed guard?

6.42 Maintenance and Repair

Pumps, as any other equipment, need preventive maintenance and periodic repair. A proper maintenance program will allow you to obtain satisfactory service from your pumps and minimize any potential safety hazards.

Remember your routine inspections will help you prolong the life of your pump and other equipment. Figure 6.9 identifies "danger" areas on pumps. These "danger" areas could be safety hazards to operators or areas where the pump could fail.

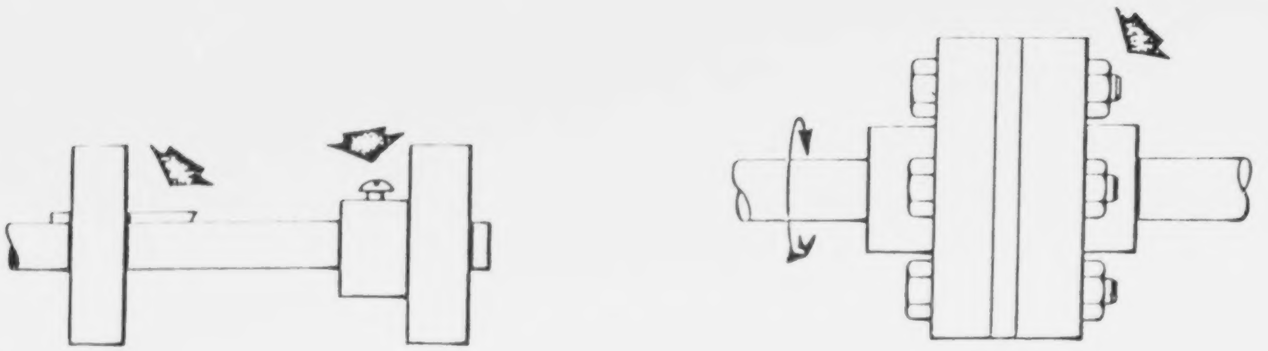
CAUTION

Do not operate a pump against a closed discharge valve, otherwise overheating will occur.

Whenever maintenance is to be performed on pumps or any other equipment, the work must be carefully planned and coordinated with other operators and the operation of the facilities. Good planning includes figuring out how to do the job from start to finish. Planning includes identifying potential safety hazards *BEFORE* starting a job and deciding how they can be avoided. To do a job safely, use the proper tools and equipment and *ISOLATE THE PUMP AND/OR EQUIPMENT FROM THE POWER SOURCE.*

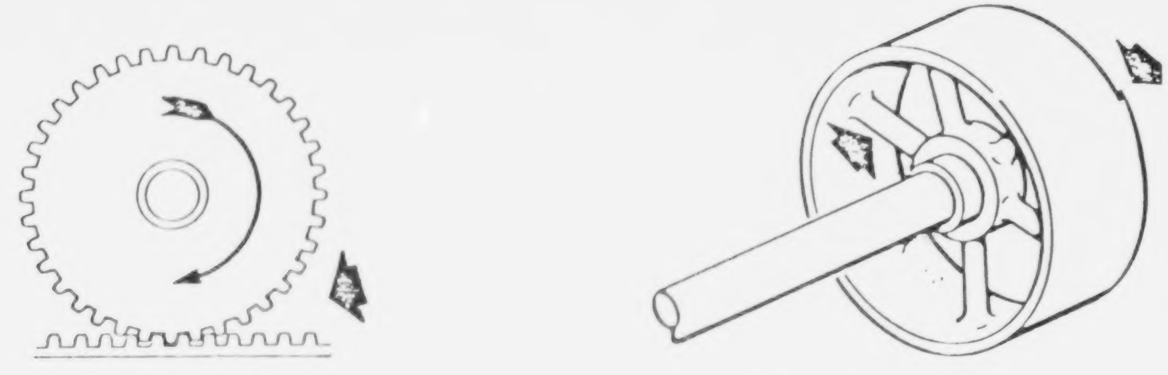
Isolate power by throwing the appropriate switches and circuit breakers, locking them out, and tagging the locks with your name on the tag. The tag must be clearly visible. Only the person who signed the tag can turn the power back on. Power can also be isolated by unplugging the pump or equipment. *ALWAYS ISOLATE THE POWER BEFORE BEGINNING ANY MAINTENANCE.*

Safety coordination and planning requires that supervisory personnel and all other potentially involved or affected personnel be notified and necessary approvals obtained *BEFORE* starting any maintenance work. This means that any other people who operate the equipment must be notified. If the electricity must be shut off to do any work or maintenance, all persons affected by the lack of power also must be notified. A good safety practice is to have other persons leave the work area until the job is completed so no one will accidentally turn on the power or equipment. When maintenance personnel must leave a job site for any reason, on returning they must check and be sure that the circuit is still locked out *BEFORE* resuming maintenance on the equipment.



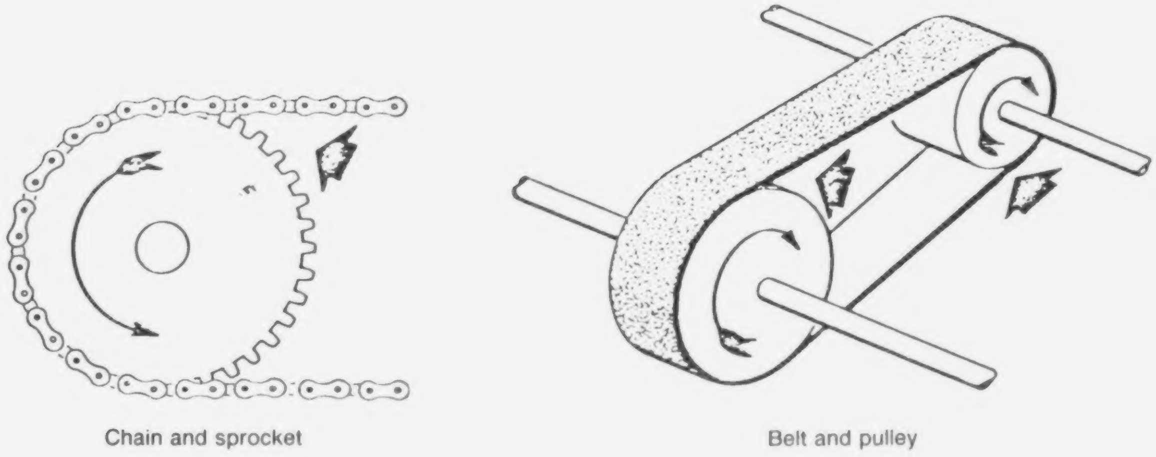
Rotating shaft and pulleys with projecting key and set screw

Rotating coupling with projecting bolt heads



Rack and gear

Rotating pulley with spokes and projecting burr on face of pulley



Chain and sprocket

Belt and pulley

NOTE: Short, thick arrows indicate danger points

Fig. 6.6 Examples of typical rotating, reciprocating, and transverse mechanisms

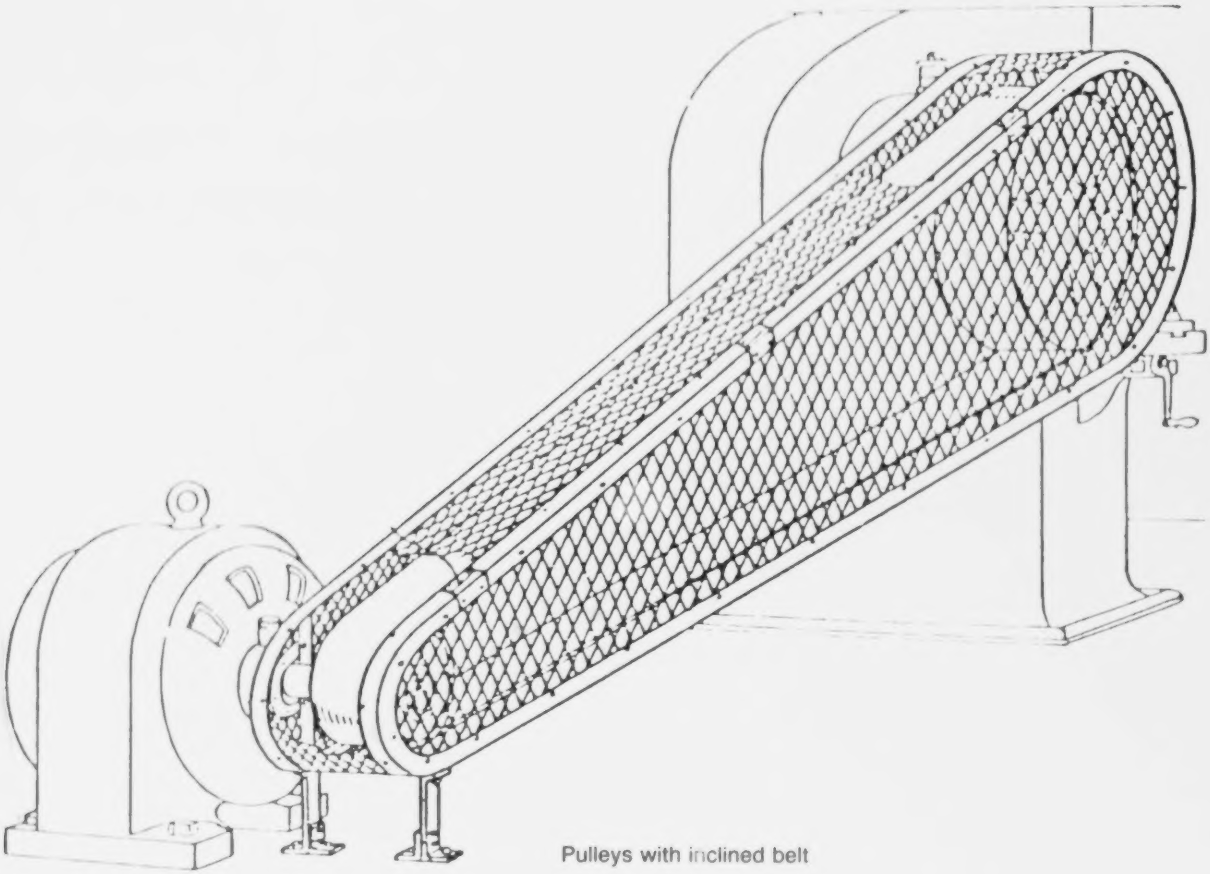
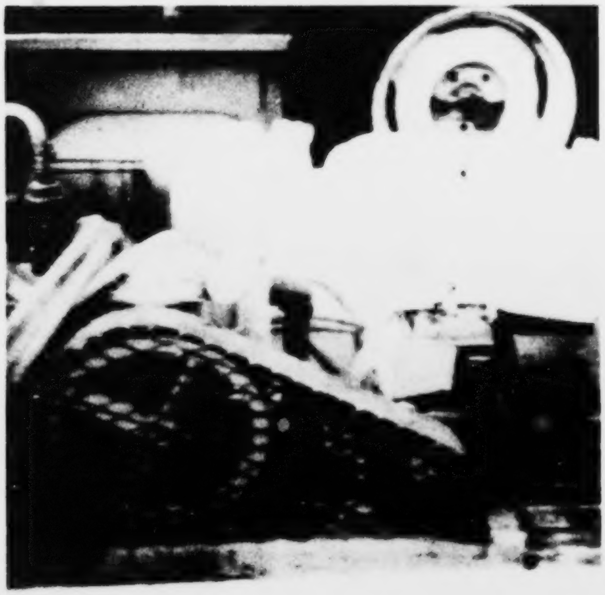
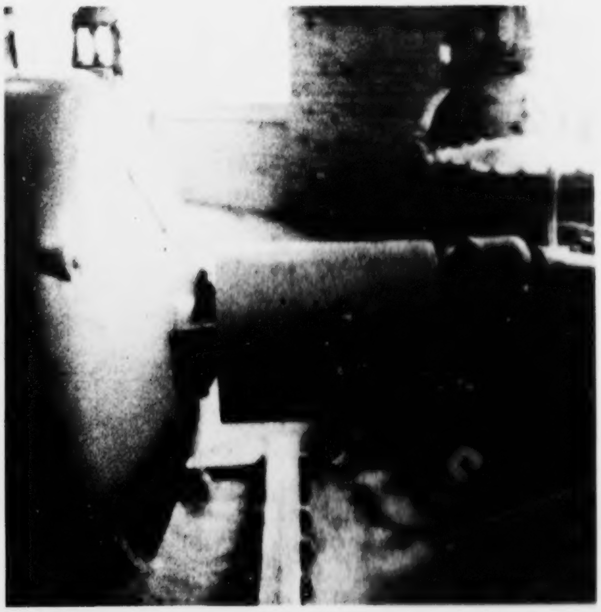

Pulleys with inclined belt

Fig. 6.7 Enclosed guard protecting operators from moving pulleys and belt

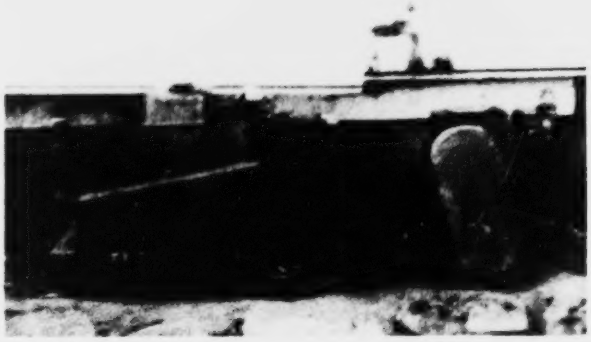


Guard over belt on gas engine



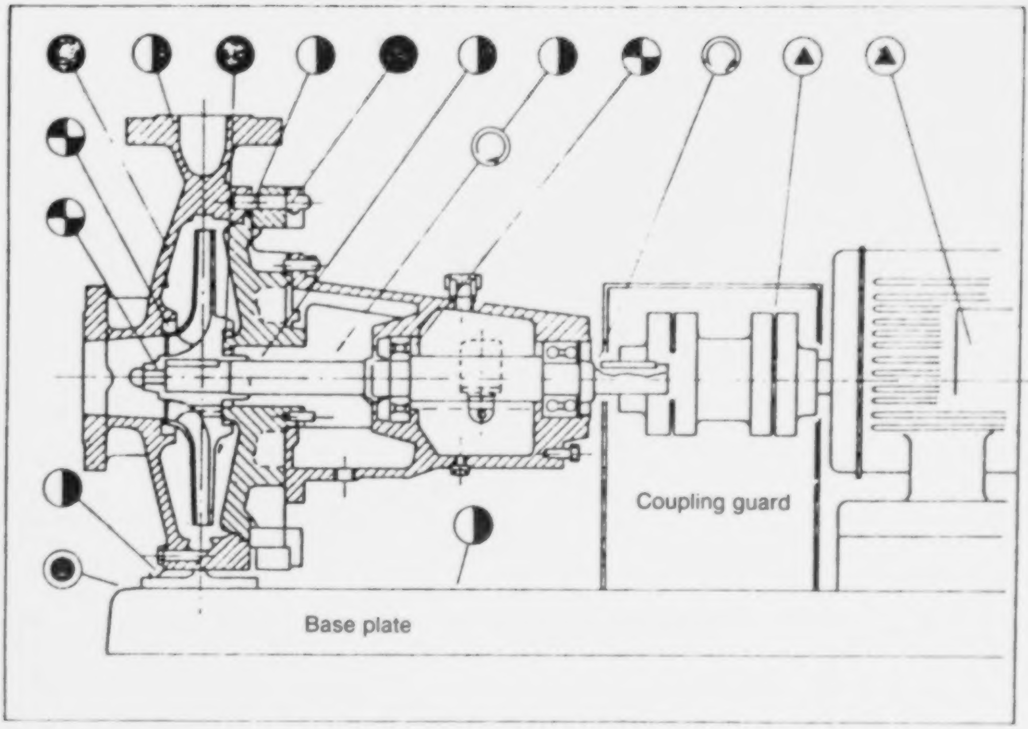
Guard over coupling

Guard on gas engine and pump



Guard on hypochlorinator

Fig. 6.8 Effective guarding systems



- ● Fracture can cause leakage and mechanical damage and injury to personnel.
- ◓ Leakage and possibility of collection of leakage (vaporizing).
- ◕ Seizure of parts or other mechanical failure
- ↻ Rotating parts area needs protection and care
- ◉ Lifting facility
- ▲ Electric protection and or sparks possibility

Fig. 6.9 "Danger" areas on pumps

If, or when, the electrical circuit must be turned back on, all persons in the area must be notified that the current is going to be turned back on again.

When equipment may be operated by a standby or backup power source, this power source must also be isolated so the equipment cannot be energized. When emergency standby engines and pumps must be maintained that are started by a battery, the battery must be disconnected and the fuel source shut off. Appropriate warning signs and tags must be posted where they are visible indicating that the power source is disconnected.

ALWAYS ISOLATE EQUIPMENT FROM THE DRIVING SOURCE BEFORE STARTING ANY WORK.

If a stationary pump or motor must be moved, use a lifting sling. Attach the sling properly to the equipment and lift the equipment up off the base. Set the pump or motor down on a cart or pallet and transfer the pump or motor to a work shop for repair or another location as necessary.

NEVER LEAVE ANY EQUIPMENT HANGING FROM A SLING IN MID-AIR. NEVER WORK ON EQUIPMENT WHEN IT IS HANGING FROM A SLING. ALWAYS LOWER EQUIPMENT TO THE FLOOR, SET IT ON A CART, OR PLACE IT ON A WORK BENCH BEFORE STARTING MAINTENANCE.

When transferring pumps or equipment from one location to another, use a sturdy cart, truck or transfer the equipment on a pallet by using a fork lift. Many operators have seriously injured their backs attempting to lift and carry heavy pumps, motors and other equipment.

6.43 Storage of Lubricants and Fuel

Lubricants and fuels must be stored in a separate facility from other storage areas because of the potential fire hazard. Clean up all spills immediately and keep the area neat and clean. A fire extinguisher must be readily available near the storage facility, but never inside the facility.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

6.4E What should be done before beginning maintenance on a pump?

6.4F What is safety planning and coordination?

6.4G Why should you never work on equipment hanging from a sling in mid-air?

6.4H Why should lubricants and fuels be stored in a separate facility from other storage areas?

6.5 WORKING IN STREETS

6.50 Definition of Terms

Before we discuss how to work safely in streets, let's review some of the terms we'll use.

WORK SITE — general place where a construction or maintenance operation is taking place.

WORK SPACE — space set apart which is identified for use by workers and equipment performing work which is protected, marked, or signed to exclude vehicular and pedestrian traffic.

TRAFFIC CONTROL — the process of advising motorists and pedestrians as to detailed requirements or conditions affecting road use at specific places and times in order that proper action may be taken and accidents or delays avoided.

Work site traffic control applies to maintenance and construction activities or other special temporary conditions affecting road use at specific places and times.

TRAFFIC CONTROL DEVICE — all signs, signals, markings and devices placed on or adjacent to a street or highway by a public body or official having jurisdiction to regulate, warn, or guide traffic. Traffic Control Devices are used to slow and guide traffic and to warn motorists of changes or possible changes in conditions.

TRAFFIC CONTROL ZONE — the entire area of the roadway which encompasses all traffic control devices used to warn, regulate or guide drivers through or around a work site.

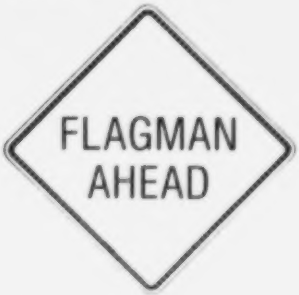
ROADWAY CLOSURE — the taking of some portion of the roadway for the exclusive use of workers, materials, or equipment during a construction or maintenance operation. Traffic is excluded from the closed portion and must use the remaining portion of the roadway if any exists. The option exists to close a portion of a lane or one or more travel lanes.

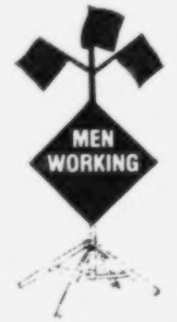
6.51 Work Area Protection

All work done in streets and highways must be performed in accordance with city, local and state regulations regarding work in roadways. In many locations a roadway encroachment permit must be obtained *BEFORE* starting work.

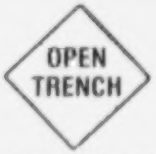
Most work area accidents on streets and highways can be attributed to the lack of proper advance warning, signing and guidance. Speed of traffic and the increased maintenance of utility lines under our streets have created hazards for the motorists. We must channel traffic flow through a work area safely with the following items considered.

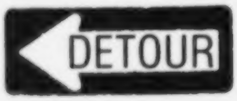
1. PREWARN
   Give the motorist time to THINK and REACT to avoid construction hazards.



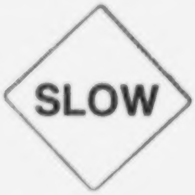


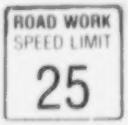
2. SIGN PROPERLY
   Use the standard shapes, sizes and colors designated by your state highway or transportation agency.



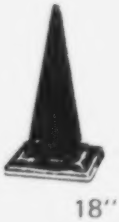


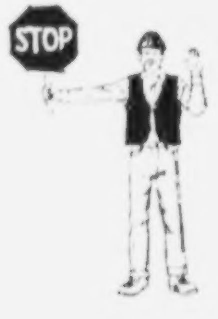
3. REGULATE SPEED
   The motorists' speed must be controlled so they may proceed safely through the construction area with a minimum of inconvenience.





4. GUIDE PROPERLY
   The driver must be directed through the work area by clearly indicated instructions and traffic devices (traffic cones).





The person installing these devices should drive through the area as another motorist would. This is a final check to determine if the work area protection system is actually effective.

6.52 Setting Up Equipment in Streets

The most common cause of worker fatality is an accident involving moving vehicles. Personnel of a water utility are exposed to this potential hazard because of work necessary to install, repair and/or operate valves in the street. Operators must work in manholes, open trenches, regulation vaults and on roadway shoulders. Any type of work in the street, roadways, or within a highway right-of-way increases the potential for hazard not only because of the nature of the job, but is also complicated because of the added problems of motorists and pedestrians.

Each job has its particular hazard which should be reviewed in a *TAILGATE SAFETY MEETING.*[7] All aspects of the job should be reviewed and someone should be responsible for each particular part of the job in order to make the job safe.

To make a job safe in the street will require:

1. Good planning,
2. Adherence to safety standards,
3. Adequate supervision, and
4. Frequent inspection.

Traffic control systems are used on street work sites to protect the:

1. Work force,
2. Motorist,
3. Pedestrian,
4. Equipment, and
5. The facility.

Traffic control procedures are used at work sites to:

1. Warn motorists and pedestrians of hazards involved and to advise them of the proper manner to travel through the area,
2. Inform the drivers of changes in regulations or additional regulations that apply to traffic through the area,
3. Guide traffic through and around the work site, and
4. Identify areas where traffic should not operate.

Whenever workers (personnel working on the street) are exposed to vehicular traffic, they should wear in addition to their normal clothing, a high visibility shirt, poncho, vest or coat. This clothing should be colored red or safety orange. A safety hat (hard hat) should be worn whenever you are near traffic.

Some jobs will require a flagman to help control the work space. Flagmen are required where:

1. Workmen or equipment intermittently block a traffic lane;
2. One lane must be used for two directions of traffic (a flagman is required for each direction of traffic); and
3. The safety of the public and/or workmen requires it.

All flagmen must wear an orange jacket or vest for daytime use and a reflectorized belt and suspender harness for use at night. During the day, flagmen use a double-sided sign paddle with "Slow" printed on one side and "Stop" on the other. At night a flashlight with red lens is used.

The flagmen should be positioned at least 100 feet (30 m) in front of the work space and a sign reading "Flagman Ahead" should be placed as far ahead of the flagmen as practical (500 feet or 150 meter minimum). Figure 6.10 shows flagmen and hand signaling motions and devices. Flagmen are expected to regulate and control the flow of traffic in a safe and orderly fashion. Flagmen and utilities have been sued because improper actions by flagmen caused an accident.

Effective placement of signs and barricades can make work sites in streets safe places to work. You must follow local safety regulations regarding the locations and types of signs to protect your agency from lawsuits if an accident occurs. However, you should study each work site and make any necessary improvements to insure a safe area to work.

The following pictures and descriptions will give you some ideas on how to establish safe work sites.

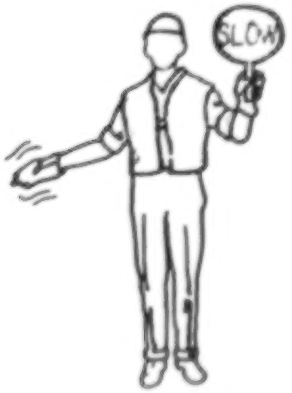
Barricades are placed in a manner to give ample warning to drivers who are planning a right turn. Traffic inconvenience is minimized. Employees are protected while working in a difficult location.

---

[7] *Tailgate Safety Meeting. The term TAILGATE comes from the safety meetings regularly held by the construction industry around the tailgate of a truck.*

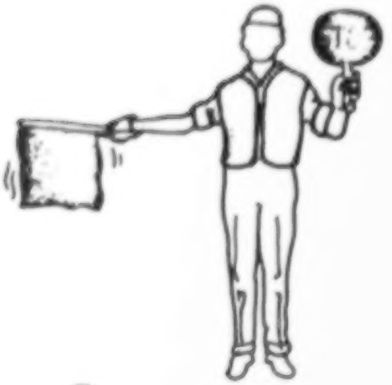
TO *SLOW* DAYTIME TRAFFIC

To Slow Traffic
(Short up and down motion
with extended right hand.)



TO *STOP* DAYTIME TRAFFIC

To Stop Traffic
("Stop" paddle high enough
to be above garment.)



TRAFFIC PROCEED

Traffic Proceed
(Never use a flag or paddle
as a signal to move traffic.)

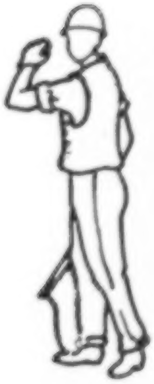


Fig. 6.10 Flagmen and hand signaling motions and devices

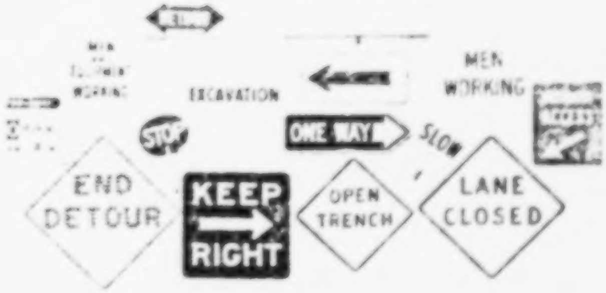
This work area on a busy thoroughfare required considerable planning to achieve free movement of vehicles past the area. Two lanes are provided in the direction of heaviest daytime traffic flow.

MORE WATER
FOR FAST GROWING
LOS ANGELES
YOUR COOPERATION
IN THIS NECESSARY CONSTRUCTION
IS APPRECIATED

This sign, though not strictly a work area protection device, helps promote customer acceptance and understanding of the necessity for important construction work.

A work area of considerable length on a major metropolitan artery. All trucks and equipment are contained within the area. Barricades serve dual purpose by warning motorists and also giving employees an audible warning in the event a vehicle crashes into the work area.

Job site located in the number two lane of a six lane boulevard. Directional signs channel traffic smoothly around the work area.


EXCAVATION
MEN WORKING
STOP
ONE WAY
SLOW
END DETOUR
KEEP RIGHT
OPEN TRENCH
LANE CLOSED

Many construction signs are available to help direct motorists and pedestrians through construction areas with a minimum of inconvenience.

Suggested distances for the spacing of delineators (traffic cones) and warning devices or signs are summarized in Table 6.4.

TABLE 6.4 SUGGESTED DISTANCES FOR WARNING DEVICES[a]

TRAFFIC CONES

MPH	Distance in Feet
Up to 30 mph	10-20 feet
30 to 40 mph	25-35 feet
45 to 55 mph	40-50 feet

HIGH LEVEL WARNING DEVICE PLACEMENT GUIDES

MPH	Distance in Feet
25 mph or below	150 feet
35 mph	250 feet
45 mph	500 feet
55 mph	750 feet

[a] Contact your state highway department or transportation agency for your regulations.

The following figures are some typical setups for working in the street (Figures 6.11, 6.12 and 6.13).

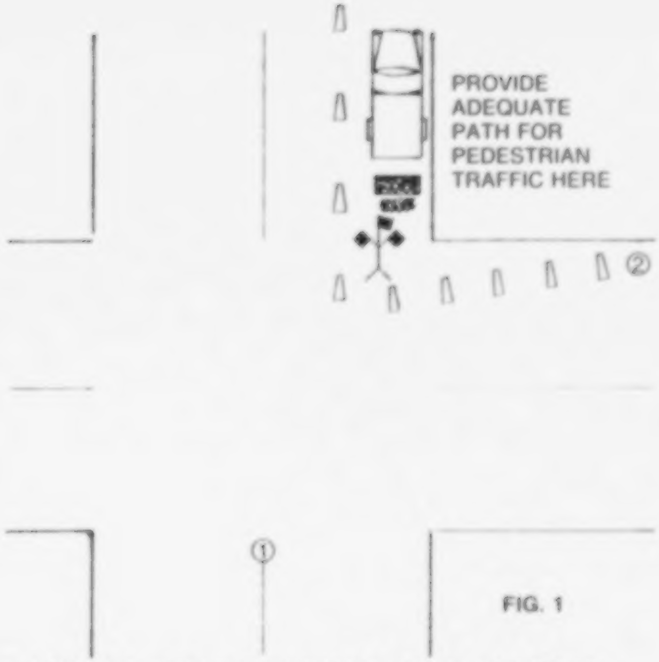

PROVIDE
ADEQUATE
PATH FOR
PEDESTRIAN
TRAFFIC HERE
②
①

FIG. 1

PLACEMENT NEAR INTERSECTION. SOME LOCATONS MAY REQUIRE HIGH LEVEL WARNINGS AT POINTS ① ②

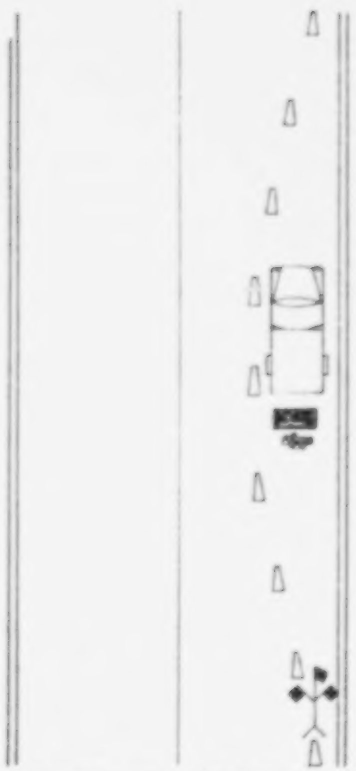


FIG. II

NORMAL SERVICE, LEAK OR CONSTRUCTION PLACEMENT. SEE TABLE 10.4 FOR DISTANCES.

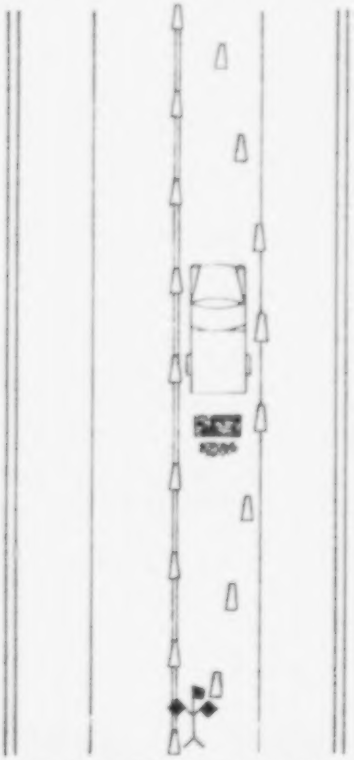


FIG. III

MULTI-LANE HIGHWAY PLACEMENT. PLACE HI-LEVEL WARNING IN SAME LANE AS OBSTRUCTION. SEE TABLE 10.4 FOR DISTANCES.

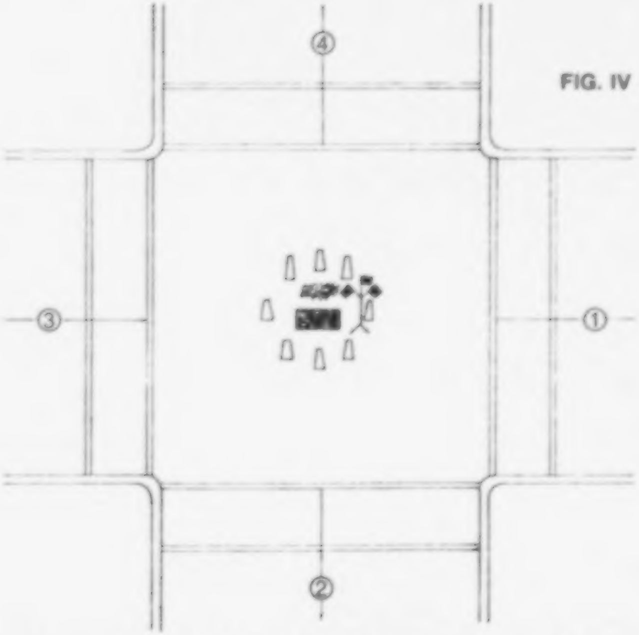


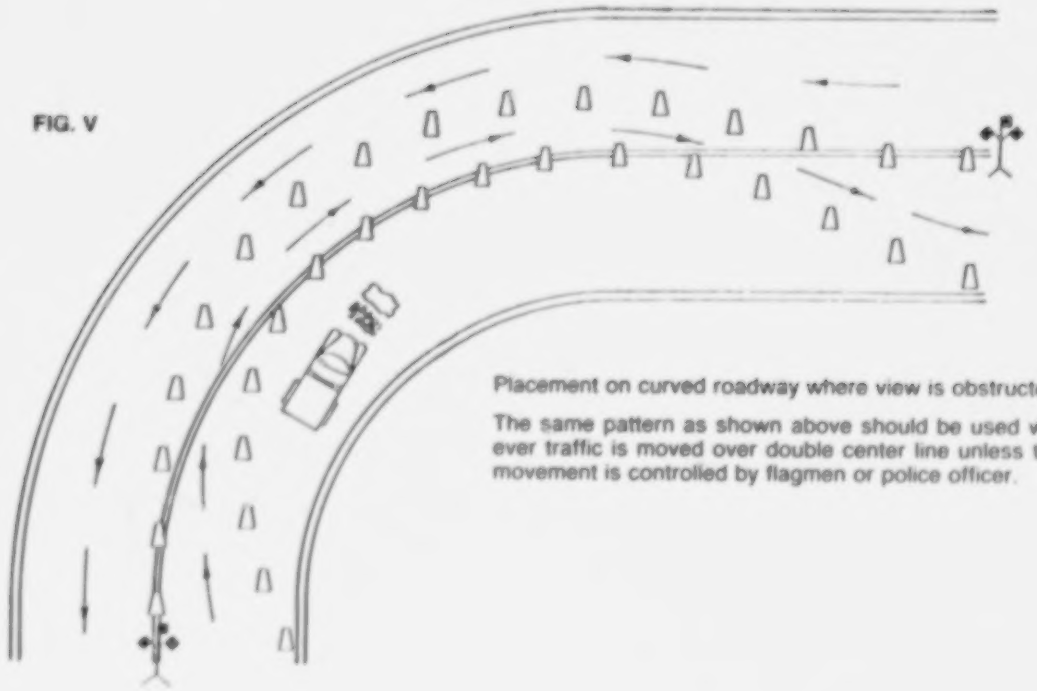
FIG. IV

PLACEMENT AT MAJOR TRAFFIC SIGNAL CONTROLLED INTERSECTION WHERE CONGESTION IS EXTREME. SOME LOCATIONS MAY PERMIT WARNINGS AT POINTS 1 2 3 4.

Fig. 6.11 Placement of traffic cones and signs

TYPICAL HIGH-LEVEL WARNING

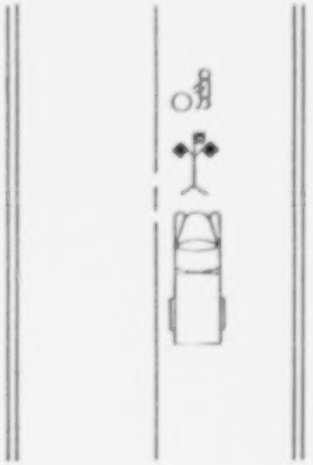
FIG. V



Placement on curved roadway where view is obstructed.

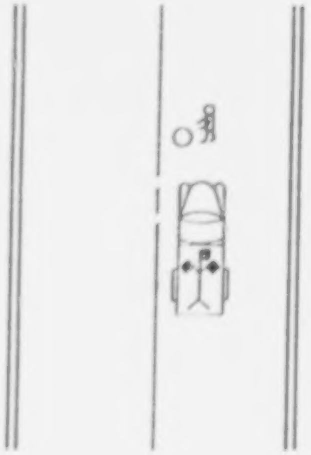
The same pattern as shown above should be used whenever traffic is moved over double center line unless traffic movement is controlled by flagmen or police officer.

FIG. VI



Placement for gate operation or other jobs of short duration. Employee must wear high visibility red jacket.

FIG. VII



Alternate method for operation described at left. High-level warning is mounted on rear of vehicle that is parked in advance of work location. Employee must wear high visibility red jacket.

Fig. 6.11 Placement of traffic cones and signs (continued)

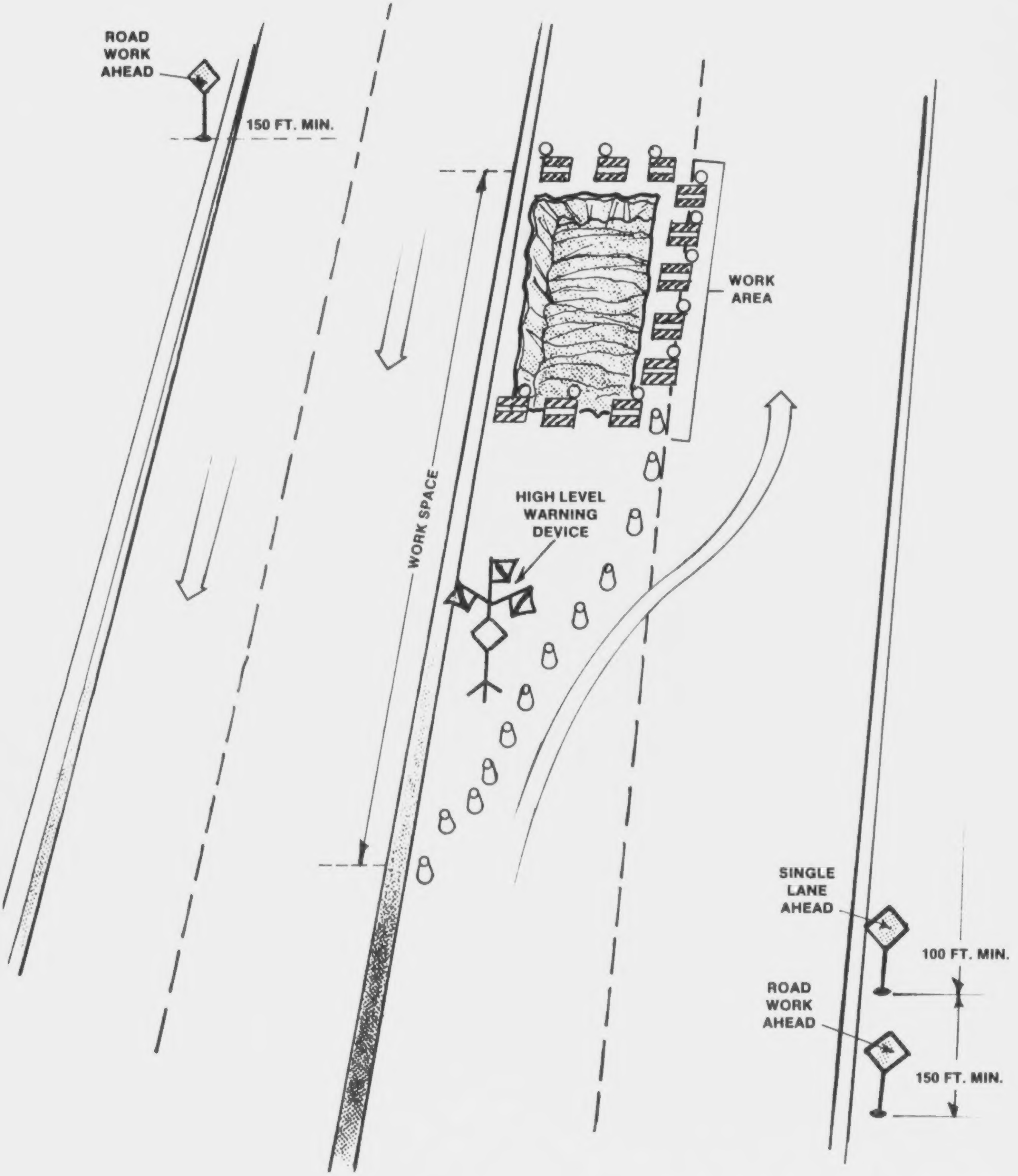

ROAD
WORK
AHEAD
150 FT. MIN.
WORK
AREA
WORK SPACE
HIGH LEVEL
WARNING
DEVICE
SINGLE
LANE
AHEAD
100 FT. MIN.
ROAD
WORK
AHEAD
150 FT. MIN.

Fig. 6.12 Closing of left lane

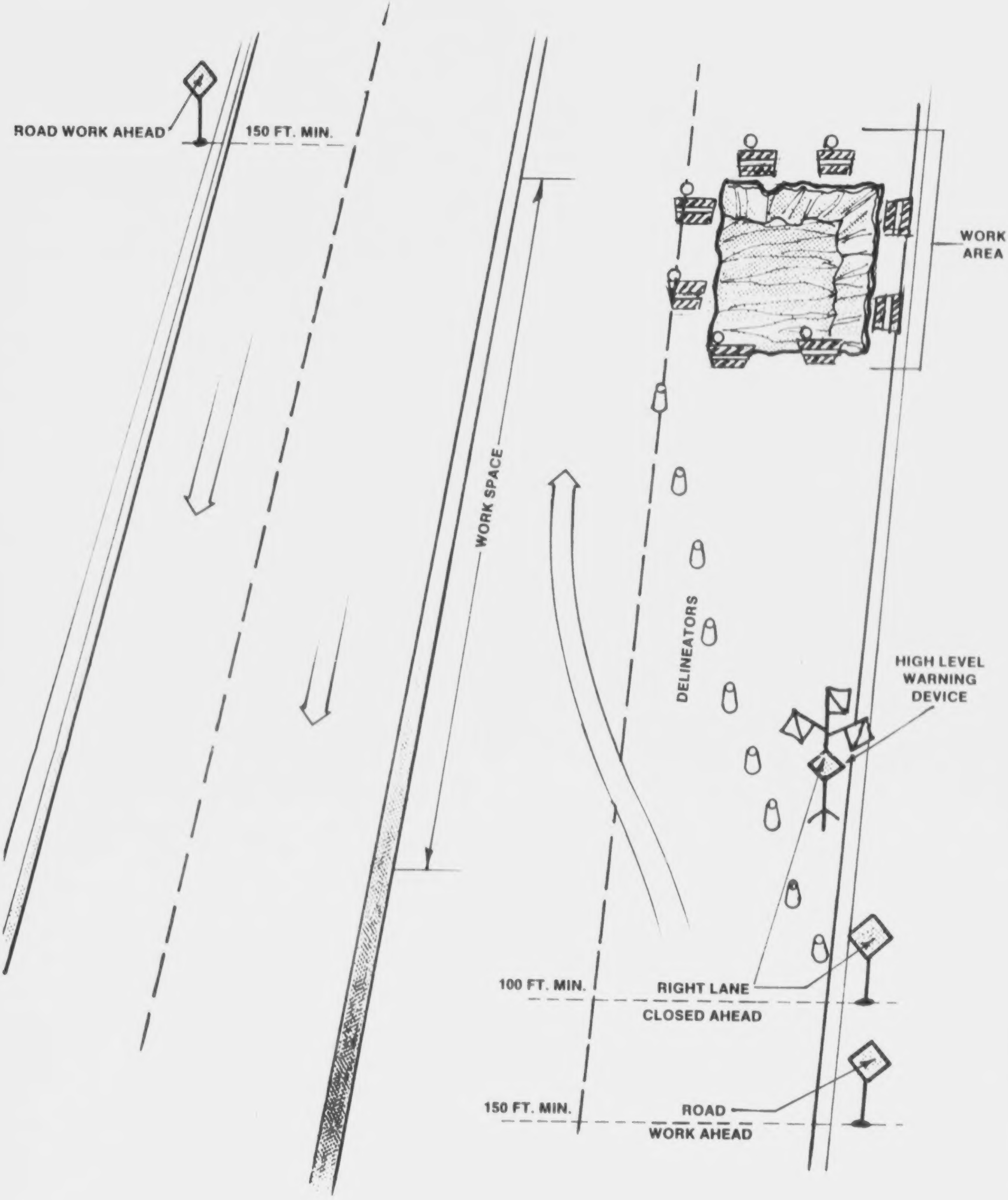

ROAD WORK AHEAD
150 FT. MIN.
WORK AREA
WORK SPACE
DELINEATORS
HIGH LEVEL WARNING DEVICE
100 FT. MIN.
RIGHT LANE CLOSED AHEAD
150 FT. MIN.
ROAD WORK AHEAD

Fig. 6.13 Closing of right lane

Accidents associated with work on the street are a prime indicator of a breakdown in the traffic control system. Any accident that occurs at the work site should be analyzed to determine whether adjustments to the traffic control zone are needed. The time you spend to properly protect the work space with traffic controls may save your life. Figure 10.14 illustrates some good practices in work area protection.

6.53 Tailgate Topic on Street Warning Devices

Each job in a roadway presents problems in methods of giving motorists adequate warning of our presence. Whenever there are new mains to be laid, mains repaired, or mains relocated because of freeway construction, you may be required to work in traffic. All this construction has a bad effect on the motorist in one respect; drivers pay less attention to work going on in the street, and they do not slow down in many cases where they pass our jobs.

HE SAID SLOW, TURKEY!
SLOW

Our only protection is to give the motorist sufficient warning by use of barricades, cones and flagmen. Placement of signs requires careful thought. Some job locations can present real problems when insuring safety for all concerned. We all know most of the established rules for placing warning devices. A review of some of these rules may remind us of a few points we forget to consider.

1. Whenever possible, use a flagman when setting up or breaking down the work area.
2. Use more, rather than too little, warning equipment at the work area.
3. Anticipate the unexpected and irrational acts of pedestrians and vehicles.
4. Do not use the same setups on streets with fast moving traffic as would be used on slow traffic streets.
5. Keep all tools and materials within the confines of the protected work area.

These are just a few points to consider. Every job is different. Use good safety judgment and past experience as a guide. Remember, we not only want to set up the job so we are obeying the law, we want to go even further and set up so an accident can't happen.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

6.5A What items should be considered when channeling traffic flow through a work area?

6.5B What should persons who must work on streets wear?

6.5C List the hand signaling motions commonly used by flagmen.

6.5D List the rules that should be considered when setting up street warning devices.

6.54 Excavations[8]

6.540 Safety Rules for Excavations

Excavations are necessary to install or repair water lines in streets or roadways. Regulations and requirements governing excavations may be found in your state construction safety orders or other similar documents. A permit may be required for any excavations four feet (1.2 meters) or more in depth in which personnel must work. Shoring is also required.

General safety rules include:

1. Employer must inspect any excavation for hazards from possible moving ground before employees may work in or adjacent to the excavation.
2. Excavations must be inspected by qualified persons after each rain storm, earthquake or other hazard.
3. Large excavations must be inspected daily.
4. Properly qualified supervisors must be on site at all times during excavations.
5. Safety provisions must be taken to protect workers installing or removing shoring systems.
6. Spoil (material removed from excavation) must be kept back at least four feet (1.2 m) from the edge of all excavations.
7. Safe and convenient access to an excavation must be provided.
8. Effective barriers must be installed at excavations adjacent to mobile equipment.
9. Water must not be allowed to accumulate in any excavation.

6.541 Trenches

A trench is an excavation in which the average depth exceeds the width and the width is 15 feet (4.5 meters) or less at the bottom. The same general requirements which apply to excavations apply to trenches. Trenching is more common than excavations in water utility work. Exits must be provided at 25-foot (7.4-meter) intervals for all occupied trenches four or more feet (1.2 m) deep.

Covers placed over trenches in roadways must be secured against displacement. Covers are usually placed over a trench at the end of the day. This provides for opening of the street for peak traffic flow. Occasionally excavations or trenches must cross sidewalks or other pedestrian rights of way. When this is necessary, a safe, temporary right of way must be provided or foot traffic should be rerouted.

Figure 6.15 illustrates various types of trench shoring conditions.

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[8] *Also see Chapter 3, Distribution System Facilities, Section 3.653, "Excavation and Shoring," in WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE.*

1. Truck and spoil bank placed ahead of excavation to provide employee protection.
2. Cone pattern arranged with gentle curves — traffic adjusts smoothly.
3. Pipe blocked to prevent rolling into street. Barricades provide pedestrian warning.
4. Material neatly stacked.
5. High level warning or barricades of solid material to give audible warning of vehicles entering work area.
6. Pedestrian bridge over excavation.
7. Left side of truck protected by cone pattern, work area entirely outlined.
8. Tools out of way of pedestrians, tools not in use replaced in truck.
9. Pickup parked in work area or on street away from work area.

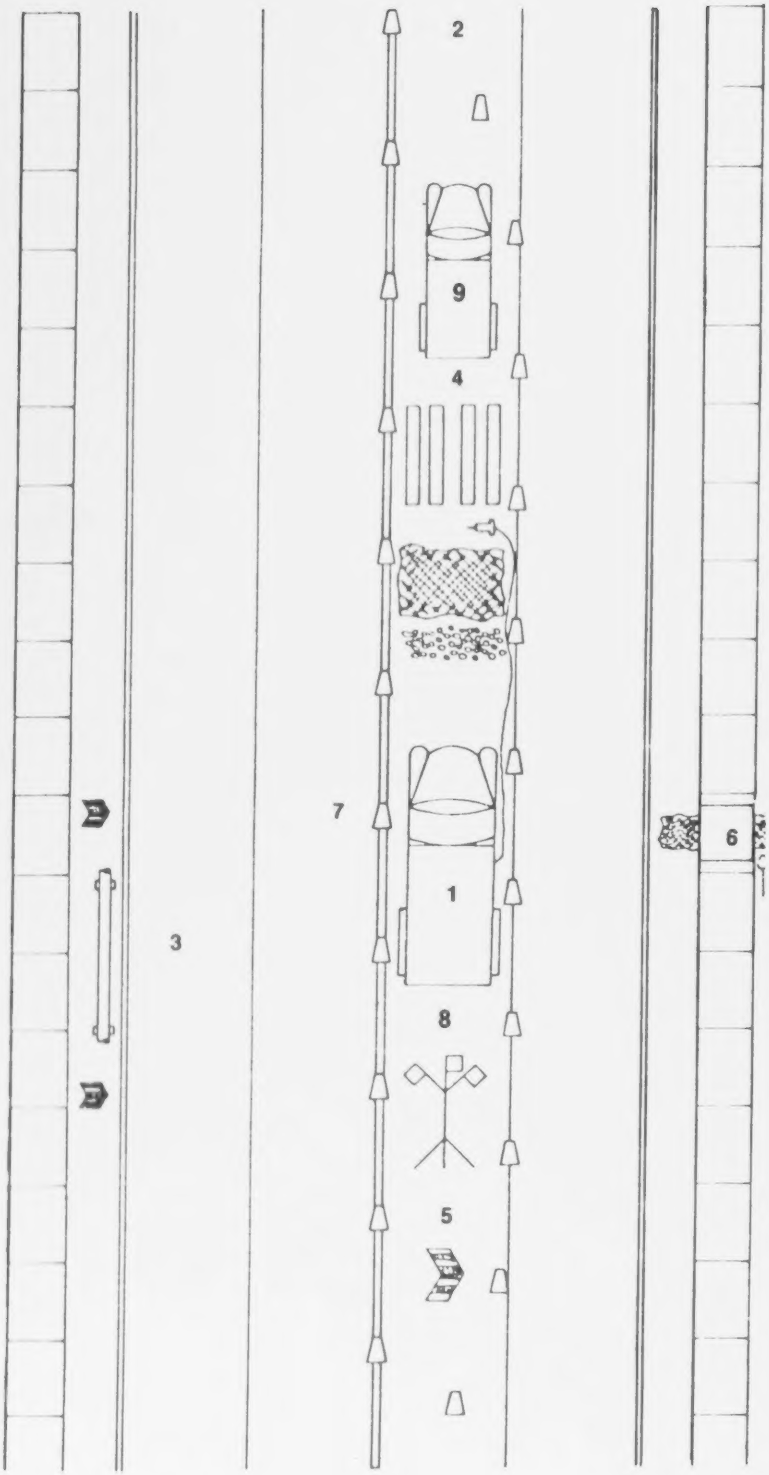


Fig. 6.14 Good practices in work area protection

RUNNING MATERIAL

Sheet Piling or equivalent solid sheeting is required for trenches four feet or more deep.

Longitudinal-stringer dimensions depend upon the strut braces, the stringer spacing, and the depth of stringer below the ground surface.

Greater loads are encountered as the depth increases, so more or stronger stringers and struts are required near the trench bottom.

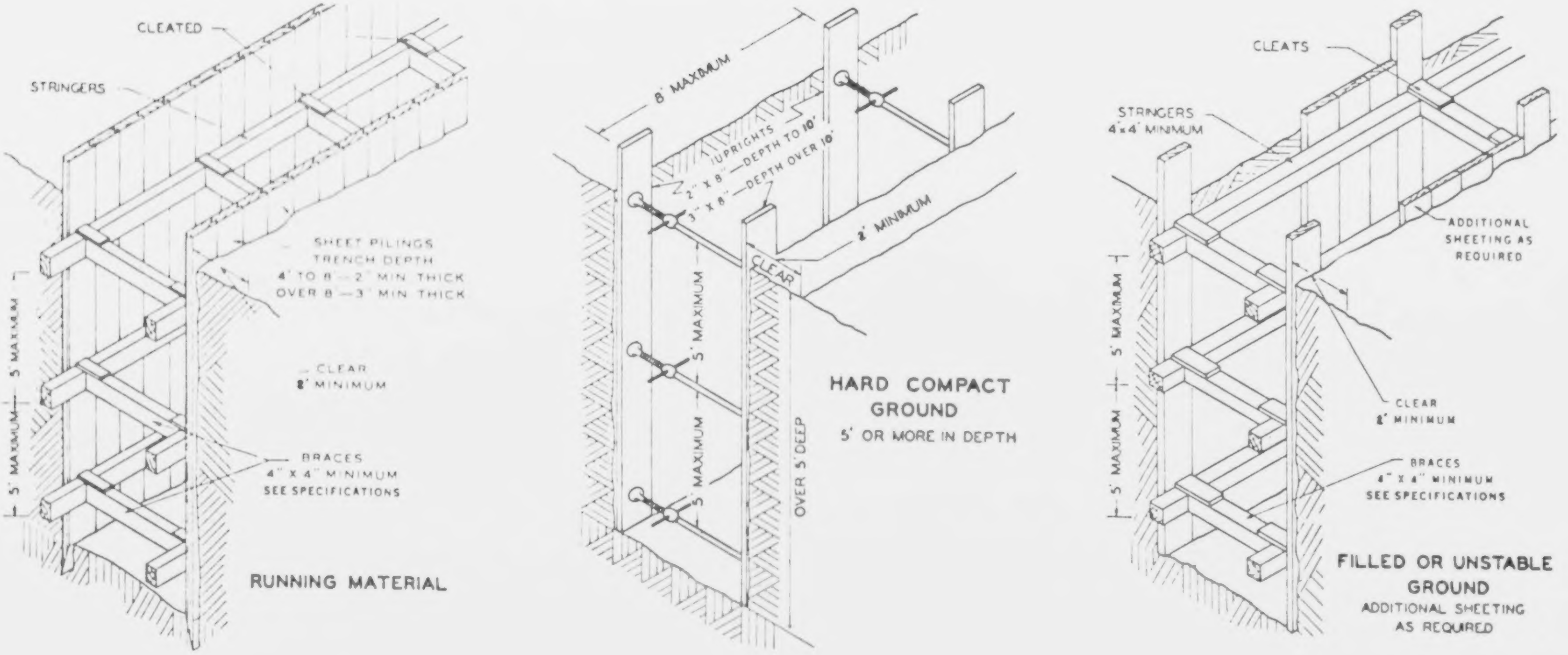
HARD COMPACT GROUND

Trenches 5 feet or more deep and over 8 feet long must be braced at intervals of 8 feet or less.

SATURATED, FILLED OR UNSTABLE GROUND

Sheeting must be provided, and must be sufficient to hold the material in place.

Longitudinal-stringer dimensions depend upon the strut and stringer spacing and upon the degree of instability encountered.


CLEATED
STRINGERS
SHEET PILINGS
TRENCH DEPTH
4' TO 8' — 2" MIN THICK
OVER 8' — 3" MIN THICK
CLEAR
2' MINIMUM
BRACES
4" X 4" MINIMUM
SEE SPECIFICATIONS
5' MAXIMUM
5' MAXIMUM
8' MAXIMUM
UPRIGHTS
2" X 8" —DEPTH TO 10'
3" X 8" —DEPTH OVER 10'
2' MINIMUM
CLEAR
5' MAXIMUM
5' MAXIMUM
OVER 5' DEEP
CLEATS
STRINGERS
4"x4" MINIMUM
ADDITIONAL
SHEETING AS
REQUIRED
CLEAR
2' MINIMUM
BRACES
4" X 4" MINIMUM
SEE SPECIFICATIONS
5' MAXIMUM
5' MAXIMUM

RUNNING MATERIAL

HARD COMPACT GROUND
5' OR MORE IN DEPTH

FILLED OR UNSTABLE GROUND
ADDITIONAL SHEETING AS REQUIRED

Fig. 6.15 Various types of trench shoring conditions

6.542 Cave-Ins

Improper shoring can contribute to cave-ins. Many cave-ins can be avoided by using the proper shoring where warranted by soil type and condition. Also, proper shoring procedures can avoid the embarrassing situations of finding oneself in a position of helplessness while installing the bottom brace or screw jack first simply because it is the path of least resistance. That is the easy way, but not the safe way.

Another hazard is the excavated spoil bank. Usually the spoil bank is set back far enough to prevent the material from falling back into the trench and also far enough to provide a walkway or tool-rest for shovels and crowbars. Of great significance, however, is the fact that the proper setback of the spoil bank will keep the weight away from the edge of the trench. If the spoil is too heavy and too close to the edge, the wall of the trench could cave in on top of you.

The following procedures are recommended in order to prevent violations of the safety rules, to prevent cave-ins, and to help keep us from getting hurt.

1. In excavations five feet (1.5 meters) or deeper (four feet in some regulations), shoring is required and the spoil bank is to be kept back a minimum of two feet (0.6 meters) from the edge of the trench. Increase this distance consistent with the type and condition of the soil.
2. When installing braces or screw jacks, start with the top one first and progressively work downward. Removal is in reverse order, starting with the bottom brace and working upward.
3. Eight feet (2.4 meters) is the maximum spacing of uprights under the ideal conditions of hard, compact soil excavated to a depth not exceeding ten feet (3 meters). Spacing of the uprights shall be decreased and solid sheathing may be required when the depth exceeds ten feet (3 meters) or if unstable soil is encountered.
4. When sources of external vibration (trucks, railroads) are nearby, special safety precautions may be necessary. Additional bracing or other effective means are recommended.
5. In trenches four feet (1.2 meters) or deeper, ladders or ramps should be provided for access and should be located so that workers need not move farther than 25 feet (7.5 meters). The ladders should extend a minimum of 30 inches (75 cm) above the top of the excavations.

Field inspections and injury reports have indicated that the items listed above are frequently overlooked. Attention to these items is necessary if we are to reduce accidents in this area. If we continue to ignore safety regulations, the pain and suffering of accidents will continue.

The economic impact of shoring requirements is a known factor. Provision of the proper materials, equipment and the time to install and remove the shoring is a required expense. The installation of a substandard shoring system is just as expensive as one properly installed. Given the alternative, it makes sense to install the shoring system properly!

These requirements are minimal and, on occasion, the shoring and methods may have to be improved. In large excavations or where complex shoring systems deviate from regular shoring procedures, alternate shoring systems must be designed by a registered civil engineer and submitted to the appropriate authorities for approval.

6.543 Ladders

Ladders must be placed in excavations so that any worker is never more than 25 feet (7.5 meters) from the ladder. For example, one ladder is required for each 50 feet (15 meters) of trench if the ladder is placed in the center of the trench. If the ladder is placed near one end of the trench two ladders would be required. The ladders must extend 2½ feet (75 centimeters) above the surface of the excavation. Ladders are required in all excavations where a problem exists in entering or exiting the excavation. All ladders must be kept clean and in good repair.

6.544 WARNING: Look Out for Other Underground Utilities

Before you do any excavating, determine the location of underground utilities and advise the utility owners of the proposed work. Some underground installations that could be damaged by excavations include underground cables, electrical services, gas mains and occasionally storm water and sewer lines that may be adjacent to proposed excavations. *NEVER* disturb a thrust block supporting an underground utility. Many phone books list an "Underground Service Alert" or "One-Call" phone number which you should call *BEFORE* you do any underground digging or drilling. Figures 6.16 and 6.17 give some typical telephone company warnings and indicators of underground cable lines.

6.55 Protect the Public

When the work area crosses the sidewalks, walkways or crosswalk areas, special consideration must be given to pedestrian safety. Every effort must be made to separate the pedestrian from the work area. Protective barricades, fencing, handrails and bridges must be used with warning devices and signs to direct foot traffic to areas where pedestrians may pass safely. Walkways in construction areas should be at least four feet (1.2 meters) wide and free of abrupt changes in grade. Where traffic must change grade, an incline should be used. Special consideration should be given to the blind and handicapped. There should be a minimum vertical clearance of seven feet (2.1 meters) and illumination should be provided during hours of darkness. Occasionally, a walkway must be closed completely. When this is necessary, foot traffic should be diverted at the closest crosswalks with the appropriate signs and barricades (Figure 6.18).

When welding is necessary on the job, suitable screens must be placed to protect the public from arc welding flash or sparks from cutting operations.

When equipment is stored on the job site, such as pipe, it should be securely blocked so it cannot be displaced.

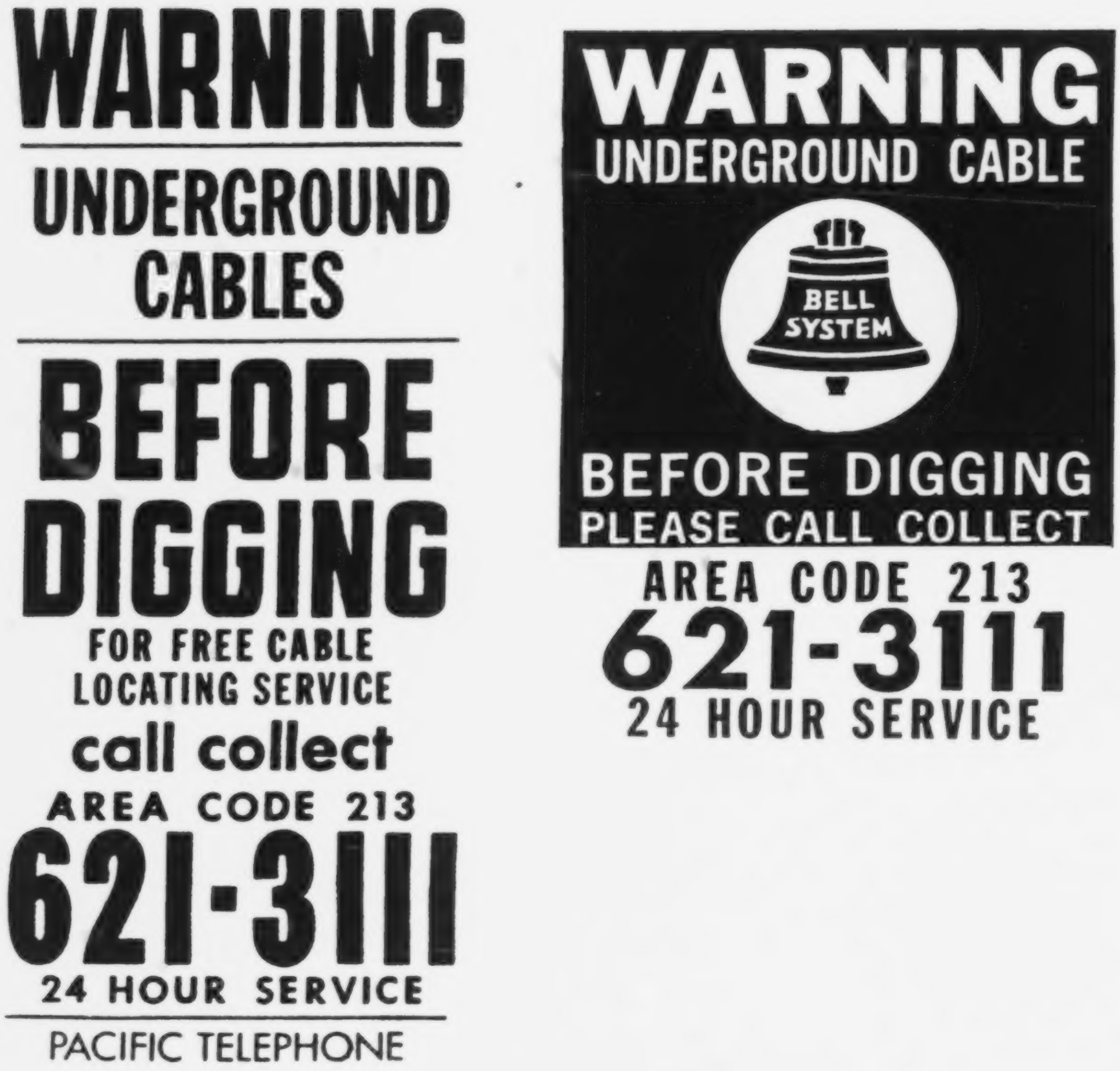

WARNING
UNDERGROUND CABLES
BEFORE DIGGING
FOR FREE CABLE LOCATING SERVICE
call collect
AREA CODE 213
621-3111
24 HOUR SERVICE
PACIFIC TELEPHONE
WARNING
UNDERGROUND CABLE
BELL SYSTEM
BEFORE DIGGING
PLEASE CALL COLLECT
AREA CODE 213
621-3111
24 HOUR SERVICE

Fig. 6.16 Typical identification and warning signs used by a phone company to identify facilities

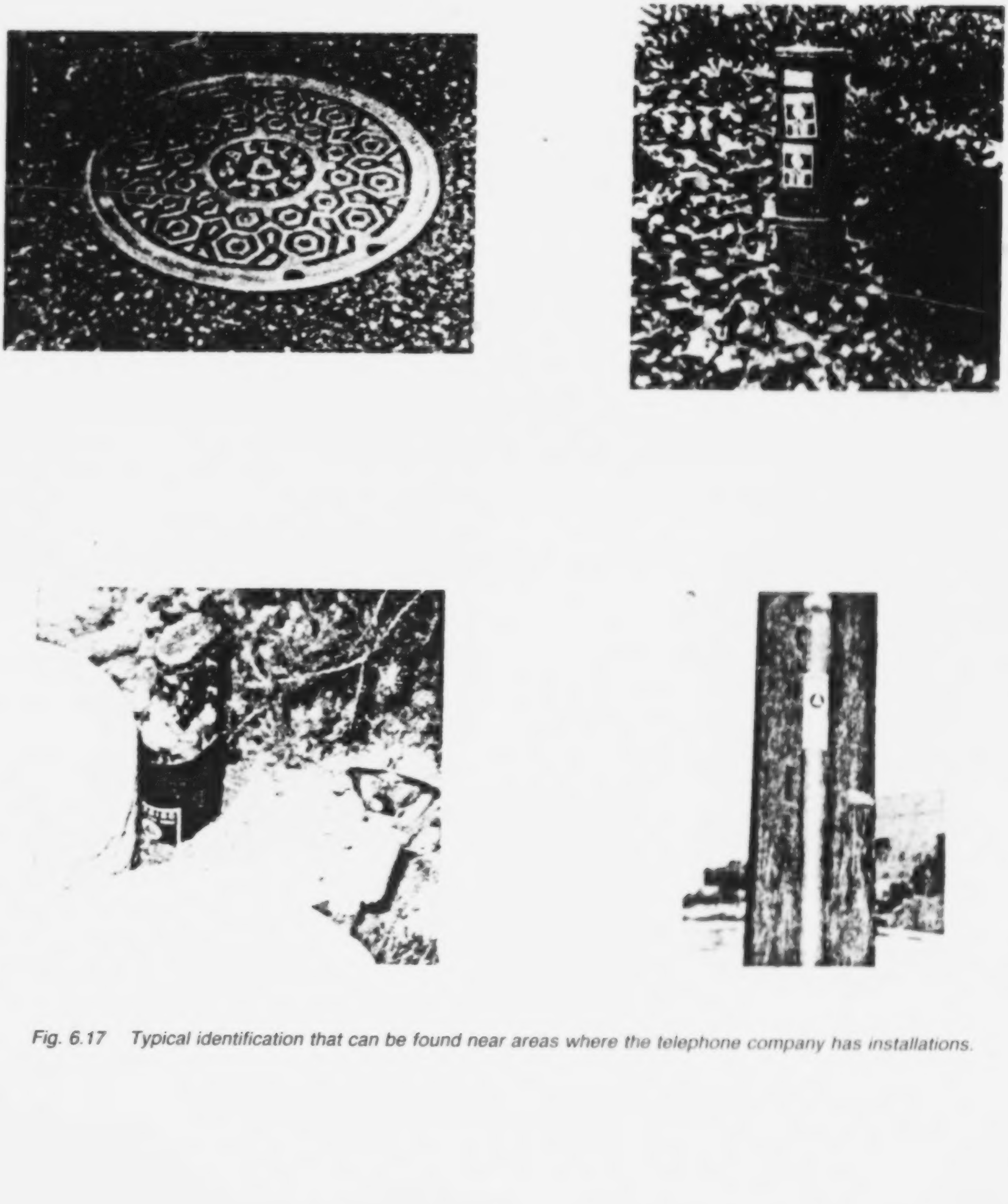


Fig. 6.17 Typical identification that can be found near areas where the telephone company has installations.

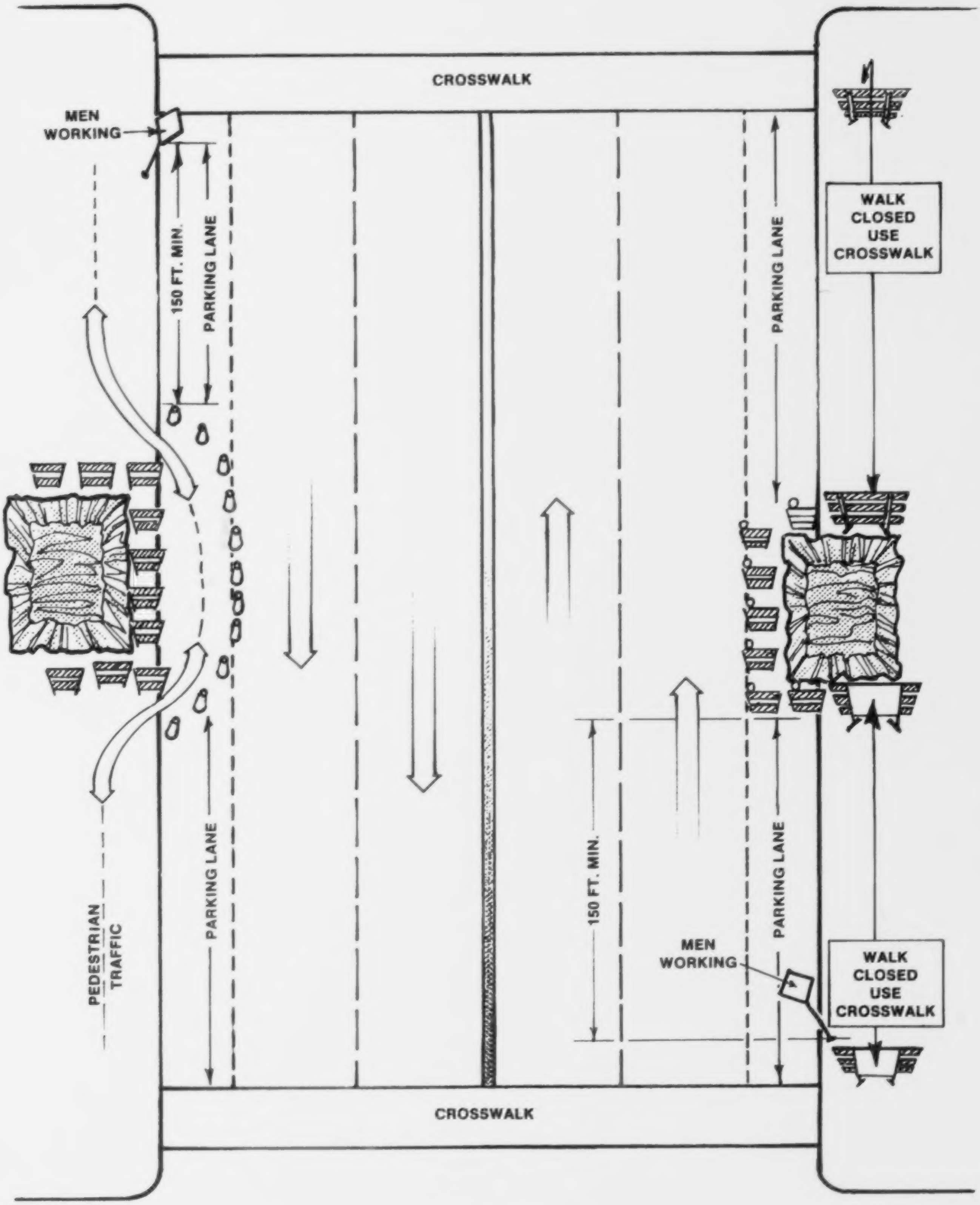

CROSSWALK
MEN WORKING
150 FT. MIN.
PARKING LANE
PARKING LANE
WALK CLOSED USE CROSSWALK
PEDESTRIAN TRAFFIC
PARKING LANE
150 FT. MIN.
PARKING LANE
MEN WORKING
WALK CLOSED USE CROSSWALK
CROSSWALK

Fig. 6.18 Pedestrian control

When work is to be done in a residential area, it is good public relations to advise the public what is to be done, how long it is expected to take, that all safety regulations will be observed, and that every effort will be taken not to disrupt the routine of the neighborhood.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

6.5E List the general safety rules for an excavation.

6.5F What type of shoring material should be used with trenches in running material?

6.5G List the underground utilities that could be damaged by water utility personnel searching for a leaking underground water main.

6.5H What would you tell the public when excavation work is planned in a residential neighborhood?

6.6 SAFETY AROUND WATER STORAGE FACILITIES

6.60 Slips and Falls

Industrial accident reports indicate that approximately 25 percent of all accidents are caused by slips and falls. The water utility industry is no different than other industries. Operators suffer from too many accidents due to slippery, wet surfaces. Slippery surfaces are common around storage facilities. They are caused by water or chemical spills on the floor. When cleaning a storage facility, one cannot avoid working on a wet surface.

When you must work inside a water tank, wear boots which have a special tread to help prevent a person from slipping. The area around a storage facility may be wet and could be the cause of slimes and growths which create slippery surfaces. Since rubber boots with special anti-slip tread are not always available, it may be necessary to treat the wet, slippery surface. There are many anti-slip coatings commercially available. Many of these anti-slip coatings may be applied with a brush, rollers or sprayed. These coatings usually have an abrasive (carbide crystals or ground walnut shells) substance suspended in a resin and use of them can change a slippery surface to a safe non-slip surface.

In addition to coatings, there are other products which you might consider. These are special treated strips of tape-like materials which can be affixed to areas where foot traffic is heavy. This type of tape material is often affixed every 6 to 12 inches (15 to 30 cm) along a slippery walkway.

6.61 Ladders

6.610 Fixed Ladders (Figure 6.19)

Most storage facilities are equipped with a fixed ladder which provides the only means of access to the top of an elevated facility (tank). A fixed ladder usually consists of individual rungs which are attached to the tank. A recommended type of fixed ladder should have provisions for use of a safety belt equipped with hooks and collar. The major hazard in the use of a fixed ladder is free fall. Other hazards include falls from carrying loads, running up or down, jumping from a ladder, and reaching too far out to the side while working from the ladders. The major hazard may be eliminated by the installation and proper use of available safety climbing devices.

6.611 Climbing Safety Devices (Figure 6.19)

Climbing safety devices are intended to prevent free fall of a climber if, for any reason, the climber should lose a grip or footing. There are two basic types of safety devices available.

1. A rail or cable attached to the ladder on which a sleeve or collar travels, and
2. A sleeve or collar which is fastened to the climber's safety belt by hooks and short lengths of chain.

The safety sleeve should be of a type which can be operated entirely by the person using the device to ascend or descend without having to continuously manipulate the safety sleeve. At normal climbing speed, the sleeve or collar slides up and down without hindrance. If the climber falls, a locking trigger or friction brake is activated and automatically stops the climber's fall.

Many hazards may be minimized by training personnel in how to go up and down a ladder.

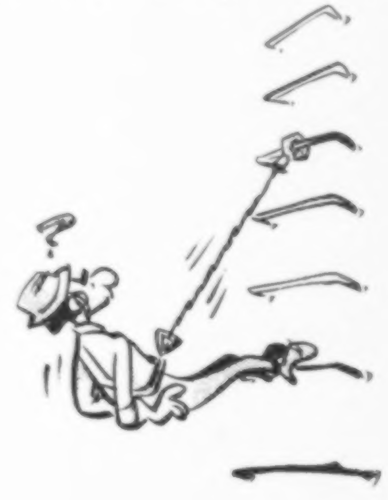
Potential ladder users should be:

1. Physically capable of exertion required, and
2. Without a previous history of heart ailment, dizzy or fainting spells, or other physical impairment which would make this climbing dangerous.

6.612 Training

Personnel should be properly trained in the use of ladders. The safe use of ladders requires two hands for the job. When climbing a ladder, use the following procedures:

1. Face the ladder and use both hands to grip the rungs or side rails firmly.
2. Place feet firmly on each rung before transferring full weight of body to each foot.
3. Climb deliberately, but without haste. Never run up or down and never slide down a ladder.
4. Never jump from a ladder. Check footing before stepping off a ladder.
5. Wear shoes with heels.
6. Always give your full attention when climbing. Be mindful that you are responsible for your own safety.



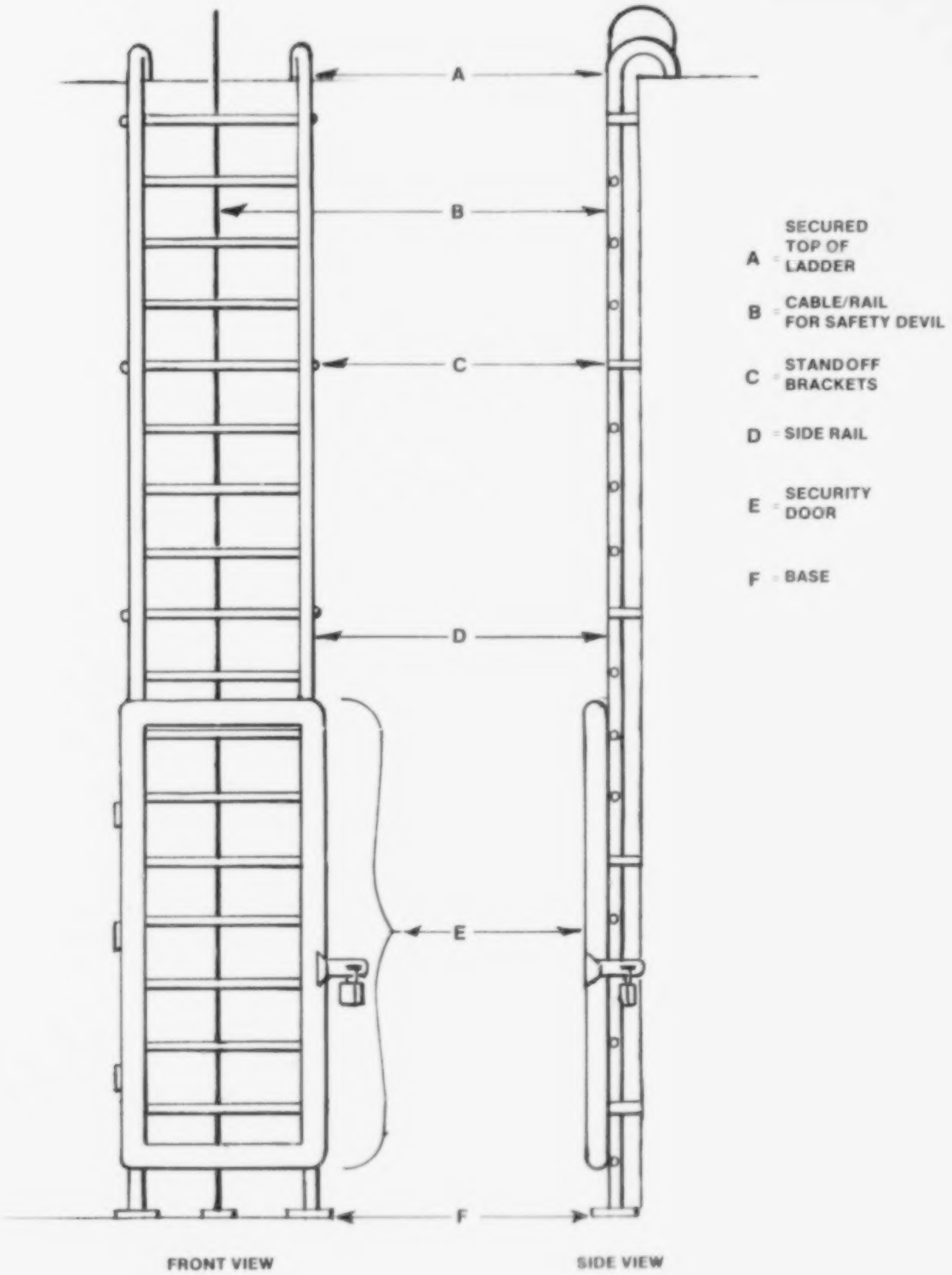

A
B
C
D
E
F
A = SECURED TOP OF LADDER
B = CABLE/RAIL FOR SAFETY DEVIL
C = STANDOFF BRACKETS
D = SIDE RAIL
E = SECURITY DOOR
F = BASE
FRONT VIEW
SIDE VIEW

Fig. 6.19 Fixed ladder with climbing safety device

6.613 Fixed Ladder Inspection

All fixed ladders and climbing devices should be inspected at least once a year. This inspection should be done by a person who is familiar with ladder inspection. Give prompt attention to correcting any defect which may be the potential cause of an accident. Some items to check for during a routine inspection include:

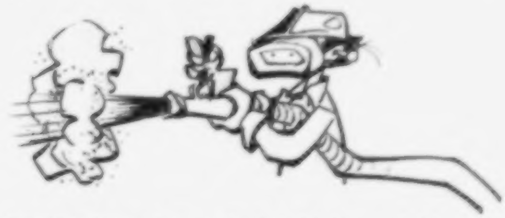
1. Loose, worn, and damaged rungs or side rails,
2. Corroded or damaged parts of the security door,
3. Corroded bolts or rivet heads where ladder is affixed to tank, and
4. Defects in climbing devices, including loose or damaged carrier rails or cables.

NEVER LEAVE A DEFECT UNCORRECTED. A ladder or safety device is only as safe as the person who is inspecting or using the ladder and climbing device.

6.62 Application of Coatings

The application of interior coatings to a storage facility (water tank) is necessary to preserve a tank interior in operating order. The application of a coating to a tank interior should not be taken lightly. Coordination and safety equipment are necessary to complete the job effectively. After the tank has been cleaned, it is recommended that it be sandblasted before applying any type of coating.

After the tank has been declared safe to enter (safe atmospheric conditions are discussed in Section 6.63, "Confined Spaces"), sandblasting may take place. The person operating the nozzle end of the sandblaster must wear protective clothing. This protection should include some type of clothing which has long sleeves — preferably a coverall type of clothing; a respirator and goggles or face shield should be used for face protection; and earplugs may be helpful because of noise.



Make certain that sufficient light is available and that sufficient air is available for the person doing the sandblasting. A respirator may not be sufficient. You may need to provide air by means of a portable air cylinder and an adequate length of air hose to a mask worn by the person doing the work.

After sandblasting has been completed, remove sand and paint debris from the tank. Make certain the tank has adequate air available for anyone working inside. After sand and debris are removed, scaffolding may be necessary for painters to apply the coating. Make certain that scaffolding meets your local safety requirements. If a mobile ladder stand is used instead of scaffolds, make certain that it meets safety requirements.

While painters are applying coating, make certain that they have air masks supplied with air and that someone is close by to check on their status periodically. Painters or any other person who must work in an enclosed area (tank) must have a safety harness with a safety line secure at the tank's entrance.

6.63 Confined Spaces

Covered water storage facilities are considered a confined space. This includes elevated tanks, facilities with roofs or covers, and underground facilities. Hazardous atmospheric conditions in confined spaces are a threat to the health of anyone who attempts to enter the facility. Other potential confined spaces encountered by operators include manholes, valve vaults, and any empty covered tank such as a dewatered filter or clear well.

When entering any confined space, the greatest consideration must be given to *DANGEROUS AIR CONTAMINATION* and *OXYGEN DEFICIENCY.* Many operators have lost their lives as a result of these two conditions. Use portable ventilation fans and *ALWAYS PROVIDE ADEQUATE VENTILATION.* Adequate ventilation will remove hazardous gases and replenish the oxygen. *BEFORE* entering a confined space test the atmosphere with gas detection instruments capable of detecting and measuring explosive gases, toxic conditions, and/or oxygen deficiency (see Section 6.20, "Monitoring Equipment"). These instruments should sound an alarm and/or produce a flashing light whenever hazardous atmospheric conditions are detected. Operators working in confined spaces should not be expected to read meters and determine whether or not a hazard exists. Operators who work around these conditions should be trained in applying artificial respiration.

Use the buddy system. Wear a safety harness and be certain your buddy is trained and knows what to do in the event that you get into trouble.

Safety is a must — never cut corners no matter how cumbersome the safety equipment may be — its use may save your life. Always review the *SAFETY NOTICE* before entering a confined space.

SAFETY NOTICE

Before anyone ever enters a tank for any reason, these safety procedures must be followed:

1. Test atmosphere in the tank for toxic and explosive gases and for adequate oxygen. Contact your local safety equipment supplier for the proper types of atmospheric testing devices. These devices should have alarms which are activated whenever an unsafe atmosphere is encountered;
2. Provide adequate ventilation, especially when painting. A self-contained positive-pressure breathing apparatus may be necessary when painting;
3. All persons entering a tank must wear a safety harness; and
4. One person must be at the tank entrance and observing the actions of all people in the tank. An additional person must be readily available to help the person at the tank entrance with any rescue operation.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

6.6A How do anti-slip coatings prevent slippery surfaces?

6.6B What are the two basic types of safety devices used by operators when climbing fixed ladders?

6.6C What are the physical requirements for operators who must climb fixed ladders?

6.6D A safety inspection of a fixed ladder should include what items?

6.6E Why do storage tanks need interior coatings?

6.6F What atmospheric hazards may be encountered in a confined space?

6.7 WORKING NEAR NOISE

Operators must be protected against the effects of exposure to noise when the sound levels exceed the limits listed in Table 6.4. Engineering methods of controlling noise must be initiated whenever possible. If noise levels cannot be controlled within acceptable limits, operators must be provided and use approved ear plugs, muffs, and/or personal protective equipment.

TABLE 6.4 HEARING PROTECTION[a]

1. When employees are exposed to loud or extended noise, ear plugs and/or protective devices shall be provided and employees shall wear them accordingly.
2. Protection against the effects of noise exposure shall be provided when sound levels exceed those shown in rule number six. These measurements shall be made on the A-scale of a standard sound level meter at a slow response.
3. When employees are subjected to sound levels exceeding those listed in rule number six, feasible administrative and/or engineering controls shall be utilized. If such controls fail to reduce employee exposure to within the permissible noise levels listed in this table, personal protective equipment shall be provided and used.
4. Plain cotton shall not be considered acceptable as an ear plug.
5. Machinery creating excessive noise shall be equipped with mufflers.
6. Employees shall not be exposed to noise which exceeds the levels listed below for a time period not to exceed those listed below.

Duration: Hours Per Day	Sound Level:dBA Slow Response
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½ (thirty minutes)	110
one fourth (¼) hour, or less	115

6.8 SAFETY INSPECTIONS

Regular safety inspections are a good way to be sure that equipment and facilities receive a regular safety review. To insure that important items are not overlooked or forgotten, inspection forms or reports are very helpful. These forms also provide a record of who inspected what items and when Figures 6.20 and 6.21 are typical "typical" Safety Inspection Reports."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

6.7A How can operators protect themselves from excessive noise?

6.8A Why are safety inspection forms helpful?

6.9 ARITHMETIC ASSIGNMENT

There is no arithmetic assignment for this chapter.

6.10 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 19, "Treatment Plant Maintenance and Accident Prevention."
2. *TEXAS MANUAL*, Chapter 21, "Safety."
3. Chapter 20, "Safety," in *WATER TREATMENT PLANT OPERATION*, Volume II. Available from Ken Kerri, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819. Price $30.00.
4. *SAFETY PRACTICE FOR WATER UTILITIES*, M3. Obtain from Computer Services, AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235. Order No. 30003. Price to members, $16.00; nonmembers, $20.00.
5. *SAFETY TALKS*. A series of 52 lectures on common water utility safety practices. Order No. 70010. One to five subscriptions, price to members,$11.50 each; nonmembers, $14.00 each. Available from Computer Services, AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235.
6. *STANDARD FIRST AID AND PERSONAL SAFETY*. Available from your local Area Chapter of The American Red Cross. Price $5.00.

End of Lesson 2
of 2 Lessons on SAFETY

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[a] *Occupational Safety and Health Standards, Subpart G, Paragraph 1910.94, Noise Exposure*

DISCUSSION AND REVIEW QUESTIONS

Chapter 6. SAFETY

(Lesson 2 of 2 Lessons)

Write your answers to these questions in a notebook before continuing with the Objective Test on page 332. The problem numbering continues from Lesson 1.

12. Where do rotating, reciprocating and transverse (crosswise) motions on pumps create hazards?
13. Why must water utility operators work in streets?
14. Where are flagmen required?
15. How can cave-ins be prevented?
16. How can the public be protected from excavation hazards?
17. How can you reduce the chances of operators slipping and falling on slippery surfaces?

SAFETY INSPECTION REPORT
SANITARY ENGINEERING DIVISION

Location ______________________________

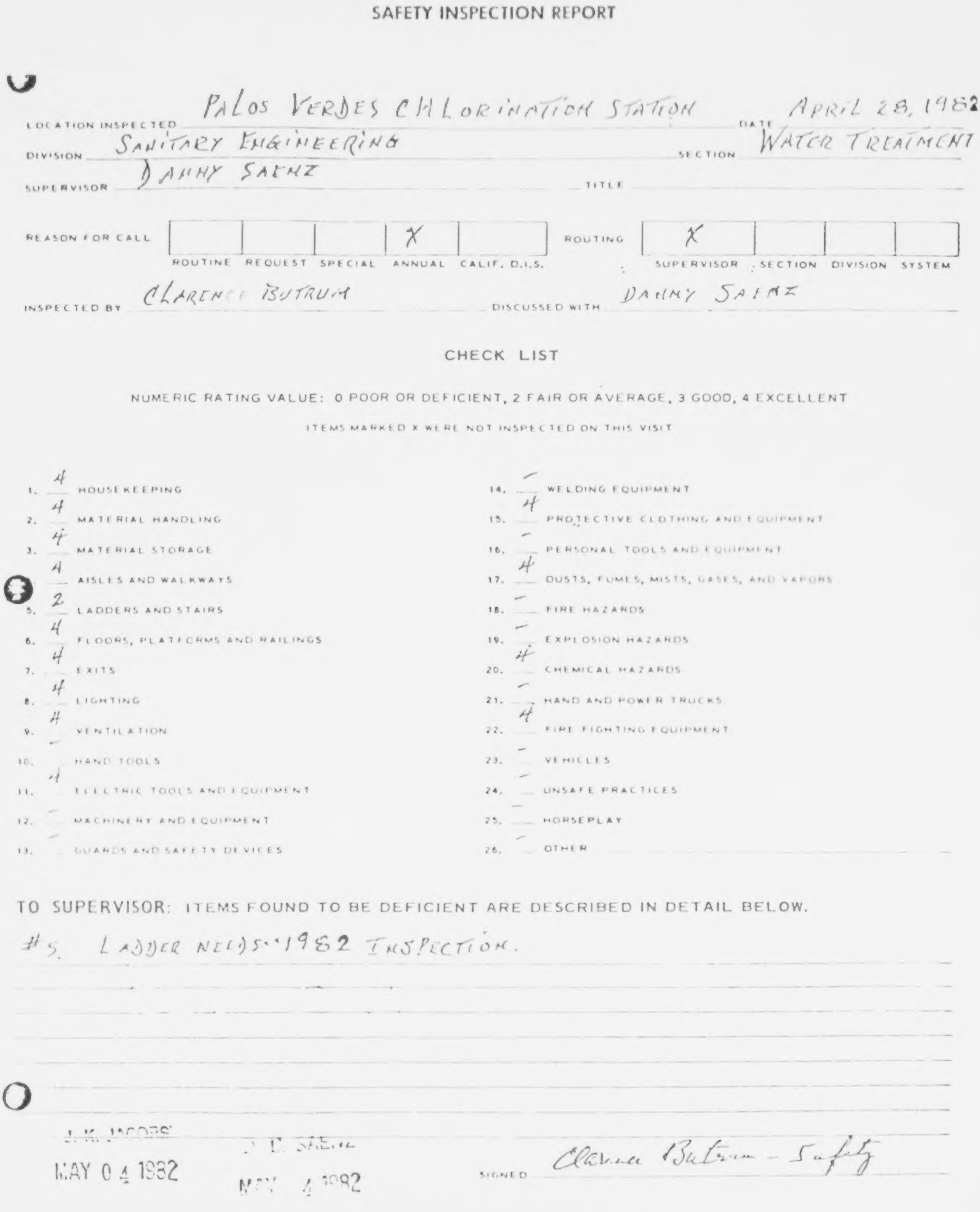
Inspec. By - Date						
Housekeeping						
Material Handling						
Material Storage						
Aisles & Walkways						
*Ladders & Stairs						
Floors & Railings						
Exits						
Lighting						
Ventilation						
Hand Tools						
Electric Equipment						
Machinery						
Safety Guards						
Safety Devices						
Clothing & Equipment						
Dusts & Fumes						
Fire Hazards						
Expolsion Hazards						
Chemical Hazards						
Fire Equipment						
Unsafe Practices						
Other						

Reviewed By - Date						

Remarks:

*Note ladders

Fig. 6.20 Safety inspection report used by operators to inspect facilities



SAFETY INSPECTION REPORT

LOCATION INSPECTED PALOS VERDES CHLORINATION STATION DATE APRIL 28, 1982

DIVISION SANITARY ENGINEERING SECTION WATER TREATMENT

SUPERVISOR DANNY SAENZ TITLE

REASON FOR CALL ☐ ROUTINE ☐ REQUEST ☐ SPECIAL ☒ ANNUAL ☐ CALIF. D.I.S.

ROUTING ☒ SUPERVISOR ☐ SECTION ☐ DIVISION ☐ SYSTEM

INSPECTED BY CLARENCE BUTRUM DISCUSSED WITH DANNY SAENZ

CHECK LIST

NUMERIC RATING VALUE: 0 POOR OR DEFICIENT, 2 FAIR OR AVERAGE, 3 GOOD, 4 EXCELLENT

ITEMS MARKED X WERE NOT INSPECTED ON THIS VISIT

1. 4 HOUSEKEEPING
2. 4 MATERIAL HANDLING
3. 4 MATERIAL STORAGE
4. 4 AISLES AND WALKWAYS
5. 2 LADDERS AND STAIRS
6. 4 FLOORS, PLATFORMS AND RAILINGS
7. 4 EXITS
8. 4 LIGHTING
9. 4 VENTILATION
10. – HAND TOOLS
11. 4 ELECTRIC TOOLS AND EQUIPMENT
12. – MACHINERY AND EQUIPMENT
13. – GUARDS AND SAFETY DEVICES
14. – WELDING EQUIPMENT
15. 4 PROTECTIVE CLOTHING AND EQUIPMENT
16. – PERSONAL TOOLS AND EQUIPMENT
17. 4 DUSTS, FUMES, MISTS, GASES, AND VAPORS
18. – FIRE HAZARDS
19. – EXPLOSION HAZARDS
20. 4 CHEMICAL HAZARDS
21. – HAND AND POWER TRUCKS
22. 4 FIRE FIGHTING EQUIPMENT
23. – VEHICLES
24. – UNSAFE PRACTICES
25. – HORSEPLAY
26. – OTHER

TO SUPERVISOR: ITEMS FOUND TO BE DEFICIENT ARE DESCRIBED IN DETAIL BELOW.

#5. LADDER NEEDS 1982 INSPECTION.

J. K. JACOBS
MAY 0 4 1982

J. E. SAENZ
MAY 4 1982

SIGNED Clarence Butrum - Safety

Fig. 6.21 Safety inspection report used by safety section personnel

SUGGESTED ANSWERS

Chapter 6. SAFETY

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 288.

6.0A Two very important aspects of a safety program are:

1. Making people aware of unsafe acts, and
2. Conducting and/or participating in regular safety training programs.

6.0B Management's responsibilities for safety include:

1. Establishing a safety policy,
2. Assigning responsibility for accident prevention,
3. Appointing a safety officer,
4. Establishing realistic goals and periodically revising them, and
5. Evaluating the results of the program.

6.0C Operators' responsibilities for safety include:

1. Performing their jobs in accordance with established safe procedures,
2. Recognizing the responsibility for their own safety and that of fellow operators,
3. Reporting all injuries,
4. Reporting all observed hazards,
5. Actively participating in the safety programs.

Answers to questions on page 289.

6.1A An accident is that occurrence in a sequence of events that usually produces unintended injury, death or property damage.

6.1B The brakes on a vehicle are working properly when they are able to stop the vehicle without grabbing or pulling to one side.

6.1C The principal reasons for unsafe acts include ignorance, indifference, poor work habits, laziness, haste, poor physical condition, and temper.

6.1D Laziness affects the speed and quality of work. Laziness also affects safety because safety requires an effort. In most jobs you cannot reduce your "safety effort" and still maintain the same level of safety, even if you slow down or lower your quality standards.

Answers to questions on page 292.

6.1E Before towing a trailer, inspect:

1. Rear, turn signal, and brake lights.
2. Tire tread and inflation,
3. Wheel attachment,
4. Trailer brake operation if equipped with brakes,
5. Safety chain.

6.1F All cigarettes and flames should be put out before attaching cables to charge a battery because a spark can ignite the hydrogen gas from the battery fluid.

6.1G Good safety practices for using boats include:

1. An annual safety inspection,
2. A safety vest or flotation device for each occupant,
3. Not overloading a boat, and
4. At least two people should go out in a boat.

6.1H A corrosive chemical is any chemical which may weaken, burn and/or destroy a person's skin or eyes.

6.1I A tailgate safety session is usually held near the work site and new and old safety hazards and safer approaches and techniques to deal with the problems of the day or week are discussed.

Answers to questions on page 295.

6.2A Some of the typical locations in a water utility where it is necessary to monitor the atmosphere before entering include underground regulator vaults, solution vaults, manholes, tanks, trenches and other confined spaces.

6.2B The standby person outside the confined area should check continuously on the status of personnel working in the confined space. Should a person working in the confined space be rendered unconscious due to asphyxiation or lack of oxygen, the standby at the surface could enter into the space by:

1. Securing a backup rescue person, and
2. Putting on the correct type of respiratory protective equipment.

6.2C A mixture of air and gas is considered hazardous when the mixture exceeds 20 percent of the Lower Explosive Limit (LEL).

Answers to questions on page 297.

6.2D Items of protective clothing for operators include:

1. Safety toe (hard toe) shoes,
2. Safety prescription glasses,
3. Safety (hard) hats,
4. Ear plugs,
5. Safety glasses (non-prescription),
6. Safety goggles,
7. Face shields,
8. Respirators and mask,
9. Canvas gloves,
10. Rubber gloves for use with corrosive chemicals,
11. Safety aprons,
12. Leggings/knee pads/safety belts or harnesses,
13. Safety toe caps, and
14. Protective clothing (lab coats or rubber suits).

6.2E Liquids spilled on floors can be cleaned up by using nonflammable absorbent materials.

6.2F The steps to safe lifting include:

1. Keep feet parted — one along the side of and one behind the object,
2. Keep back straight — nearly vertical,
3. Tuck in your chin,
4. Grip the object with the whole hand,
5. Tuck elbows and arms in,
6. Keep body weight directly over feet, and
7. Lift slowly.

6.2G Before attempting to work on electrical motors, be sure to lock out and tag all of the electrical switches.

Answers to questions on page 300.

6.3A The well operator has the responsibility to preserve the quality of the well through preventive maintenance of the area where the well is located. This responsibility also extends to good housekeeping to prevent the development of safety hazards to operators working around the well site.

6.3B A sanitary seal on a well is used to keep contaminated water and debris from entering around the well casing and reaching the groundwater.

6.3C Surface openings on top of a well that must be protected against the entrance of surface water or debris into the well include:

1. Well casing vents,
2. Gravel tubes,
3. Sounding tube,
4. Conduits, and
5. Pump motor base seal.

Answers to questions on page 301.

6.3D Hydrochloric acid must be handled carefully because it is extremely corrosive. Hydrochloric acid can burn your eyes and skin, if inhaled it will cause coughing and choking, and if swallowed will cause corrosion of your insides (including your circulatory system).

6.3E Sulfamic acid has advantages over hydrochloric acid for acid cleaning a well. Granular sulfamic acid is non-irritating to dry skin and its solution gives off no fumes except when reacting with incrusting materials. Spillage, therefore, presents no hazard and handling is easier, cheaper, and safer.

6.3F Although the granular form of sulfamic acid is non-irritating to the skin and it gives off no fumes, rubber gloves should still be used because hands may become wet from perspiration and the acid will cause burns on the skin. Safety goggles or glasses, preferably a face shield, should be used in case granules are blown into the face and/or eyes. Acid should always be added slowly to the water.

Answers to questions on page 303.

6.3G When handling hypochlorite use rubber gloves, a rubber apron, and a face shield.

6.3H Glassy phosphate should be handled very carefully because the glass particles are very sharp and can cut your skin. Use heavy duty gloves when handling. Respiration or a face shield should be worn.

6.3I If no one working for a water utility is knowledgeable about electrical circuits, the utility should contact an electrician from a local electrical firm.

6.3J Items that should be included in a safety inspection of a well site include:

1. Cleanliness of site,
2. Locks on electrical panels,
3. Fencing around site, and
4. Caution/warning signs in place.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 304.

6.4A Pumps are used to move liquids, air or gas. They are also used to increase pressures and energy of fluids.

6.4B Moving parts on a pump which require guards include rotation members, reciprocating arms, moving parts, and meshing gears. This includes rotating shafts, couplings, belts, pulleys, chains, and sprockets.

6.4C Rotating devices can injure you by gripping your clothing or hair and possibly forcing an arm or hand into a dangerous position.

6.4D The basic requirement for an enclosed guard is that it must prevent hands, arms or any other part of an operator's body from making contact with dangerous moving parts. A good guarding system eliminates the possibility of the operator or another worker placing their hands near hazardous moving parts.

Answers to questions on page 309.

6.4E *ALWAYS* isolate the power *BEFORE* beginning any maintenance on a pump.

6.4F Safety planning includes identifying potential safety hazards *BEFORE* starting a job and deciding how they can be avoided. Safety coordination requires that supervisory personnel be notified and necessary approvals obtained *BEFORE* starting any maintenance work.

6.4G Never work on any equipment when it is hanging from a sling in mid-air because the equipment could slip from the sling and fall on you.

6.4H Lubricants and fuels should be stored in a separate facility from other storage areas because of the potential fire hazard.

Answers to questions on page 317.

6.5A When channeling traffic flow through a work area, consider the following items:

1. Prewarn,
2. Sign properly,
3. Regulate speed, and
4. Guide properly.

6.5B Persons who must work in streets should wear their normal clothing plus a high visibility shirt, poncho, vest or coat. This clothing should be colored red or safety orange. A safety hat (hard hat) should be worn whenever you are near traffic.

6.5C Hand signaling motions commonly used by flagmen include (1) slow, (2) stop, and (3) proceed.

6.5D The following rules should be considered when setting up street warning devices:

1. Whenever possible, use a flagman when setting up or breaking down the work area;
2. Use more, rather than too little, warning equipment at the work area;
3. Anticipate the unexpected and irrational acts of pedestrians and vehicles;
4. Do not use the same set up on streets with fast moving traffic as would be used on slow traffic streets; and
5. Keep all tools and materials within the confines of the protected area.

Answers to questions on page 324.

6.5E General safety rules for an excavation include:

1. Employer must inspect excavations for hazards before employees may work in or adjacent to the excavation.

2. Excavations must be inspected by qualified persons after each rain storm, earthquake or other hazard.
3. Large excavations must be inspected daily.
4. Proper, qualified supervisors shall be on site at all times during excavations.
5. Safety provisions must be taken to protect workers installing or removing shoring systems.
6. Spoil must be kept back at least two feet from the edge of all excavations.
7. Safe and convenient access to an excavation must be provided.
8. Effective barriers must be installed at excavations adjacent to mobile equipment.
9. Water must not be allowed to accumulate in any excavation.

6.5F Trenches in running material should have sheet piling or equivalent solid sheeting, longitudinal stringers and cross braces.

6.5G Underground utilities that could be damaged by water utility personnel searching for a leaking underground water main include telephone cables, television cables, electrical services, gas mains and occasionally storm water and sewer lines.

6.5H When work is to be done in a residential neighborhood, it is good public relations to advise the public what is to be done, how long it is expected to take, that all safety regulations will be observed, and that every effort will be taken not to disrupt the routine of the neighborhood.

Answers to questions on page 326.

6.6A Anti-slip coatings usually have an abrasive (carbide crystals or ground walnut shells) substance suspended in a resin which can change a slippery surface to a safe non-slip surface.

6.6B The two basic types of safety devices used by operators when climbing fixed ladders are:

1. A rail or cable, which is fixed to the ladder, on which a sleeve or collar travels, and
2. A sleeve or collar which is fastened to the climber's safety belt by hooks and short lengths of chain.

6.6C Physical requirements for operators who must climb fixed ladders include:

1. Physically capable of the exertion required, and
2. Without a previous history of heart ailment, dizzy or fainting spells, or other physical impairment which would make this climbing dangerous.

6.6D A safety inspection of a fixed ladder should include checking for:

1. Loose, worn, and damaged rungs or side rails,
2. Corroded or damaged parts of the security door,
3. Corroded bolts or rivet heads where ladder is affixed to tank, and
4. Defects in climbing devices, including loose or damaged carrier rails or cables.

6.6E Storage tanks need interior coatings to preserve a tank interior in operating order.

6.6F Atmospheric hazards that may be encountered in a confined space include explosive conditions, toxic gases and/or oxygen deficiency.

Answers to questions on page 327.

6.7A Operators can protect themselves from excessive noise by using approved ear plugs, muffs, and/or personal protective equipment.

6.8A Safety inspection forms are helpful because (1) they provide a record of who inspected what items and when, and (2) they help prevent the overlooking of important safety items.

OBJECTIVE TEST

CHAPTER 6. SAFETY

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True — False

1. Safety is a form of preventive maintenance which includes equipment and machinery and its proper handling.
   1. True
   2. False
2. People miss more time from work from on-the-job accidents than from off-the-job accidents.
   1. True
   2. False
3. Offensive drivers are safe drivers.
   1. True
   2. False
4. Very few accidents related to trailer towing occur while simply coupling the trailer to the vehicle.
   1. True
   2. False
5. Boats can be safely loaded in excess of their rated capacity.
   1. True
   2. False
6. YOU are the key individual to an effective safety program.
   1. True
   2. False

7. Corrosive chemicals only have low pH values.
   1. True
   2. False
8. Sawdust should be used as an absorbent for cleaning up spilled chemicals.
   1. True
   2. False
9. New well pumps should be disinfected.
   1. True
   2. False
10. You can safely stand in water when working on electrical equipment.
    1. True
    2. False
11. Electrical equipment and wiring must be protected from environmental deterioration.
    1. True
    2. False
12. Enclosed guards permit access to dangerous moving parts at all times.
    1. True
    2. False
13. While accidents due to contact with rotating objects are not frequent, the severity of injury is very high.
    1. True
    2. False
14. In order to build up head, a pump should be operated against a closed discharge valve.
    1. True
    2. False
15. Fire extinguishers should be stored inside a fuel storage area.
    1. True
    2. False
16. Proper shoring can contribute to cave-ins.
    1. True
    2. False
17. The person installing traffic control devices should drive through the area to verify the effectiveness of the work area protection system.
    1. True
    2. False
18. The major hazard in the use of a fixed ladder is free fall.
    1. True
    2. False
19. When installing shoring braces or screw jacks, start at the bottom of the trench and work up to the top.
    1. True
    2. False
20. Slippery surfaces may be caused by water or chemical spills on the floor.
    1. True
    2. False

Multiple Choice

21. Common uses of boats by water utility operators include
    1. Disinfecting product water.
    2. Inspecting reservoirs.
    3. Pumping sludge.
    4. Sampling.
    5. Surveying reservoirs.
22. Who is primarily responsible for your safety?
    1. Management
    2. You
    3. Your co-workers
    4. Your safety officer
    5. Your supervisor
23. On floors where water or chemicals are commonly spilled, cover the floors with
    1. Catwalks.
    2. Linoleum.
    3. Safety tread.
    4. Tile.
    5. Wood.
24. Slippery floors may be prevented by
    1. Collecting drips in appropriate gutters.
    2. Collecting drips in drip pans.
    3. Keeping floors covered with algae.
    4. Keeping floors slip resistant.
    5. Using splash guards to deflect drips.
25. Before starting to drive a vehicle towing a trailer
    1. Check trailer hitch and tongue.
    2. Inspect rear, turn signal, and brake lights.
    3. Inspect trailer brake operation.
    4. Observe safety chain.
    5. Observe tire tread and inflation.
26. Unsafe acts may be caused by
    1. Ignorance.
    2. Indifference.
    3. Laziness.
    4. Poor work habits.
    5. Temper.
27. A good driver
    1. Is courteous to other drivers.
    2. Knows and observes all traffic regulations.
    3. Makes sure that all the lights are operating properly.
    4. Sometimes signals in advance of any directional changes.
    5. Uses the seat belt.
28. Items in a good safety program include
    1. Appointing a safety officer.
    2. Assigning responsibility for accident prevention.
    3. Establishing a safety policy.
    4. Reporting all injuries.
    5. Reporting all observed hazards.
29. A new well could be contaminated from
    1. Contaminated packing gravel.
    2. Disinfection solution.
    3. Drilling tools and mud.
    4. Surface runoff.
    5. Topsoil falling into well.

30. Sources of pollution which may contaminate groundwater include
    1. Artesian aquifers.
    2. Mining operations.
    3. Septic tanks.
    4. Solid waste disposal sites.
    5. Subsurface leaching systems.
31. Unsafe work practices which cause handling and lifting injuries include
    1. Carrying too heavy a load.
    2. Correct gripping.
    3. Failing to observe proper hand clearance.
    4. Failing to use proper equipment.
    5. Proper lifting.
32. Typical injuries resulting from handling and lifting include
    1. Back injuries.
    2. Eye strain.
    3. Hearing loss.
    4. Hernias.
    5. Strains and sprains.
33. Moving parts on a pump which require guards include
    1. Belts and pulleys.
    2. Chains and sprockets.
    3. Couplings.
    4. Impellers.
    5. Shafts.
34. Wells which are no longer useful should be abandoned and plugged to
    1. Assure that groundwater is protected for further use.
    2. Eliminate the potential physical hazard to people.
    3. Prevent other people from using well.
    4. Protect nearby wells form contamination.
    5. Reduce maintenance costs.
35. Traffic control systems are used on street work sites to protect the
    1. Equipment.
    2. Facility.
    3. Motorist.
    4. Pedestrian.
    5. Work force.
36. A traffic delineation device is another name for a
    1. Detour.
    2. Flagman.
    3. Speed regulating sign.
    4. Traffic cone.
    5. Traffic sign.
37. Hazards encountered by operators using a fixed ladder include
    1. Falls from carrying loads.
    2. Falls from ladder caused by electricity.
    3. Jumping from ladder.
    4. Reaching too far out.
    5. Running up or down.
38. The chances of slipping and falling on slippery surfaces can be reduced by
    1. Affixing specially treated strips of tape-like materials.
    2. Applying anti-slip coats to the surfaces.
    3. Mopping up the wet surface when it becomes slippery.
    4. Preventing the growth of slime.
    5. Wearing boots with a special anti-slip tread.
39. Exits must be provided within ______ feet of every worker for all occupied trenches four or more feet deep.
    1. 25
    2. 50
    3. 75
    4. 100
    5. 150
40. Excavations must be inspected by qualified persons after each
    1. Earthquake.
    2. Hot day.
    3. Rainy day.
    4. Shift leaves the job.
    5. Time a truck goes by.

End of Objective Test

CHAPTER 7

LABORATORY PROCEDURES

by

Jim Sequeira

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OBJECTIVES

Chapter 7. LABORATORY PROCEDURES

Following completion of Chapter 7, you should be able to:

1. Work safely in a laboratory,
2. Operate laboratory equipment,
3. Collect representative samples and also preserve and transport the samples,
4. Prepare samples for analysis,
5. Describe the limitations of lab tests,
6. Recognize precautions to be taken for lab tests,
7. Record laboratory test results, and
8. Perform the following field or laboratory tests — alkalinity, residual chlorine, coliform, hardness, jar test, pH, temperature and turbidity.

GLOSSARY

Chapter 7 LABORATORY PROCEDURES

ACIDIC (uh-SID-ick) ACIDIC

The condition of water or soil which contains a sufficient amount of acid substances to lower the pH below 7.0.

ALIQUOT (Al-li-kowt) ALIQUOT

Portion of a sample.

ALKALI (AL-ka-lie) ALKALI

Various soluble salts, principally of sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical water treatment processes.

ALKALINE (AL-ka-LINE) ALKALINE

The condition of water or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

AMBIENT TEMPERATURE (AM-bee-ent) AMBIENT TEMPERATURE

Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

AMPEROMETRIC (am-PURR-o-MET-rick) AMPEROMETRIC

Based on the electric current that flows between two electrodes in a solution.

AMPEROMETRIC TITRATION AMPEROMETRIC TITRATION

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction. See TITRATE.

ASEPTIC (A-SEP-tick) ASEPTIC

Free from the living germs of disease, fermentation or putrefaction. Sterile.

BACTERIA (back-TEER-e-uh) BACTERIA

Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BLANK BLANK

A bottle containing only dilution water or distilled water; the sample being tested is not added. Tests are frequently run on a SAMPLE or a BLANK and the differences compared.

BUFFER BUFFER

A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.

BUFFER CAPACITY BUFFER CAPACITY

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT

An expression of the concentration of specified constituents in water in terms of their equivalence to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

CARCINOGEN (car-SIN-o-jen) CARCINOGEN

Any substance which tends to produce cancer in an organism.

CHLORORGANIC (klor-or-GAN-nick)
CHLORORGANIC

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.

COLORIMETRIC MEASUREMENT
COLORIMETRIC MEASUREMENT

A means of measuring unknown concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.

COMPOSITE (come-PAH-zit) (PROPORTIONAL) SAMPLES
COMPOSITE (PROPORTIONAL) SAMPLES

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

COMPOUND
COMPOUND

A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride-NaCl) is a compound.

DESICCATOR (DESS-uh-KAY-tor)
DESSICATOR

A closed container into which heated weighing or drying dishes are placed to cool in a dry environment. The dishes may be empty or they may contain a sample. Desiccators contain a substance, such as anhydrous calcium chloride, which absorbs moisture and keeps the relative humidity near zero so that the dish or sample will not gain weight from absorbed moisture.

DISINFECTION (dis-in-FECT-shun)
DISINFECTION

The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

DPD
DPD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N, N-diethyl-p-phenylene-diamine.

ELEMENT
ELEMENT

A substance which cannot be separated into its constituent parts and still retain its chemical identity. For example, sodium (Na) is an element.

END POINT
END POINT

Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs. This is called the END POINT of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

FACULTATIVE (FACK-ul-TAY-tive)
FACULTATIVE

Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food material such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

FLAME POLISHED
FLAME POLISHED

Melted by a flame to smooth out irregularities. Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.

GRAB SAMPLE
GRAB SAMPLE

A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

GRAVIMETRIC
GRAVIMETRIC

A means of measuring unknown concentrations of water quality indicators in a sample by *WEIGHING* a precipitate or residue of the sample.

INDICATOR (CHEMICAL)
INDICATOR (CHEMICAL)

A substance that gives a visible change, usually of color, at a desired point in a chemical reaction, generally at a specified end point.

INORGANIC INORGANIC

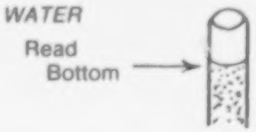
Material, such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

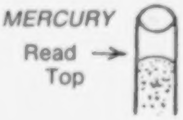
M OR MOLAR *M* OR MOLAR

A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A one *M* solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

MENISCUS (meh-NIS-cuss) MINISCUS

The curved top of a column of liquid (water, oil, mercury) in a small tube. When the liquid wets the sides of the container (as with water), the curve forms a valley. When the confining sides are not wetted (as with mercury), the curve forms a hill or upward bulge.





MILLIGRAMS PER LITER, mg/*L* MILLIGRAMS PER LITER, mg/*L*

A measure of the concentration by weight of a substance per unit volume. For practical purposes one mg/*L* of a substance in fresh water is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams. If it contains 10 milligrams of calcium, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/*L*), or 10 parts of calcium per million parts of water, or 10 parts per million (10 ppm).

MOLE MOLE

The molecular weight of a substance, usually expressed in grams.

MOLECULAR WEIGHT MOLECULAR WEIGHT

The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
O	16	4	64
			98

MOLECULE (MOLL-uh-kule) MOLECULE

The smallest division of a compound that still retains or exhibits all the properties of the substance.

MPN (pronounce as separate letters) MPN

MPN is the **M**ost **P**robable **N**umber of coliform-group organisms per unit volume of sample water. Expressed as the number of organisms per 100 m*L* of sample water.

N OR NORMAL *N* OR NORMAL

A normal solution contains one gram equivalent weight of reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A 1 *N* solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.

NEPHELOMETRIC (NEFF-el-o-MET-rick) NEPHELOMETRIC

A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

ORGANIC ORGANIC

Substances that come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical substances of mineral origin.) Also see INORGANIC.

ORGANISM ORGANISM

Any form of animal or plant life. Also see BACTERIA.

OSHA OSHA

The Williams-Steiger **O**ccupational **S**afety and **H**ealth **A**ct of 1970 (OSHA) is a law designed to protect the health and safety of industrial workers and also the operators of water supply systems and treatment plants.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDATION-REDUCTION POTENTIAL OXIDATION-REDUCTION POTENTIAL

The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

PPM or parts per million PPM

Parts per million parts, a measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/*L*) which is the preferred term.

PATHOGENIC ORGANISMS (path-o-JEN-nick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of bacteria which do *NOT* cause disease. These organisms are called non-pathogenic.

PATHOGENS (path-o-JENS) PATHOGENS

Pathogenic or disease-causing organisms.

PERCENT SATURATION PERCENT SATURATION

The amount of a substance that is dissolved in solution compared with the amount that could be dissolved in the solution, expressed as a percent.

$$\text{Percent Saturation, \%} = \frac{\text{Amount of Substance That is Dissolved}}{\text{Amount That Could Be Dissolved in Solution}} \times 100\%$$

pH (pronounce as separate letters) pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$\text{pH} = \text{Log}\,\frac{1}{(H^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered safe for domestic consumption.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or measure, detect, or examine other substances.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

SOLUTION SOLUTION

A liquid mixture of dissolved substances. In a solution it is impossible to see all the separate parts.

STANDARD SOLUTION STANDARD SOLUTION

A solution in which the exact concentration of a chemical or compound is known.

STANDARDIZE STANDARDIZE

(1) To compare with a standard. In wet chemistry, to find out the exact strength of a solution by comparing with a standard of known strength.
(2) To set up an instrument or device to read a standard. This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

STERILIZATION (STARE-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

SURFACTANT (sir-FAC-tent) SURFACTANT

Abbreviation for surface-active agent. The active agent in detergents that possesses a high cleaning ability.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge or floc. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point.

TURBIDITY UNITS (TU) (ter-BID-it-tee) TURBIDITY UNITS

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity units which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

VOLATILE (VOL-uh-tull) VOLATILE

A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.

VOLATILE ACIDS VOLATILE ACIDS

Acids produced during digestion. Fatty acids which are soluble in water and can be steam-distilled at atmospheric pressure. Also called "organic acids." Volatile acids are commonly reported as equivalent to acetic acid.

VOLATILE LIQUIDS VOLATILE LIQUIDS

Liquids which easily vaporize or evaporate at room temperatures.

VOLATILE SOLIDS VOLATILE SOLIDS

Those solids in water or other liquids that are lost on ignition of the dry solids at 550°C.

VOLUMETRIC VOLUMETRIC

A measurement based on the volume of some factor. Volumetric titration is a means of measuring unknown concentrations of water quality indicators in a sample by determining the volume of titrant or liquid reagent needed to complete particular reactions.

Chapter 7. LABORATORY PROCEDURES

(Lesson 1 of 5 Lessons)

7.0 BASIC WATER LABORATORY PROCEDURES

7.00 Importance of Laboratory Procedures

Water treatment processes cannot be controlled effectively unless the operator has some means to check and evaluate the quality of water being treated and produced. Laboratory quality control tests provide the necessary information to monitor the treatment processes and insure a safe and good-tasting drinking water for all who use it. By relating laboratory results to treatment operations, the water treatment or supply system operator can first select the most effective operational procedures, then determine the efficiency of the treatment processes, and identify potential problems before they affect finished water quality. For these reasons, a clear understanding of laboratory procedures is a must for every waterworks operator.

NOTICE

THE COLLECTION OF A BAD SAMPLE OR A BAD LABORATORY RESULT IS ABOUT AS USEFUL AS NO RESULTS. TO PREVENT BAD RESULTS REQUIRES (1) CONSTANT MAINTENANCE AND CALIBRATION OF LABORATORY EQUIPMENT AND (2) USE OF CORRECT LAB PROCEDURES. ALSO RESULTS OF LAB TESTS ARE OF NO VALUE TO ANYONE UNLESS THEY ARE USED.

7.01 Metric System

The metric system is used in the laboratory to express units of length, volume, weight (mass), concentration and temperature. The metric system is based on the decimal system. All units of length, volume, and weight use factors of 10 to express larger or smaller quantities of these units. Below is a summary of metric and English unit names and their abbreviations.

Type of Measurement	English System	Metric Name	Metric Abbreviation
Length	inch foot yard	meter	m
Temperature	Fahrenheit	Celsius	°C
Volume	quart gallon	liter	*L*
Weight	ounce pound	gram	g
Concentration	lbs/gal strength, %	milligrams per liter	mg/*L*

Many times in the water laboratory we use smaller amounts than a meter, a liter, or a gram. To express these smaller amounts, prefixes are added to the names of the base metric unit. There are many prefixes in use; however, we commonly use two or three prefixes more than any others in the laboratory.

Prefix	Abbreviation	Meaning
centi-	c	1/100 of; or 0.01 times
milli-	m	1/1000 of; or 0.001 times
micro-	μ	1/1,000,000 of; or 0.000001 times

One centimeter (cm) is 1/100 (one hundredth) of a meter, one milliliter (m*L*) is 1/1000 (one thousandth) of a liter, and likewise, one microgram (μg) is 1/1,000,000 (one millionth) of a gram.

EXAMPLES

(1) Convert 3 grams into milligrams.

1 milligram = 1 mg = 1/1000 grams

therefore, 1 gram = 1,000 milligrams

(3 grams) (1000 mg/gram) = 3000 mg

(2) Convert 750 milliliters (m*L*) to liters.

1 m*L* = 1/1000 liter

therefore, 1 liter = 1000 m*L*

(750 m*L*) (1 liter/1000 m*L*) = 0.750 liters

(3) Convert 50 micrograms (μg) to grams.

1 μg = 1/1,000,000 gram

therefore, 1 gram = 1,000,000 μg

50 μg × 1 gram/1,000,000 μg = 0.00005 grams

Larger amounts than a meter, liter, or gram can be expressed using such prefixes as kilo- meaning 1000. A kilogram is 1000 grams.

The Celsius (or centigrade) temperature scale is used in the water laboratory rather than the more familiar Fahrenheit scale.

	Fahrenheit (°F)	Celsius (°C)
Freezing point of water	32	0
Boiling point of water	212	100

To convert Fahrenheit to Celsius you can use the following formula:

Temperature, °C = 5/9 (°F-32)

EXAMPLE Convert 68°F to °C

$$\begin{aligned}\text{Temperature, °C} &= 5/9\,(\text{°F}-32\text{°F})\\ &= 5/9\,(68\text{°F}-32\text{°F})\\ &= 5/9\,(36)\\ &= 20\text{°C}\end{aligned}$$

To convert Celsius to Fahrenheit, the following formula can be used:

$$\text{Temperature, °F} = 9/5\,(\text{°C}) + 32\text{°F}$$

EXAMPLE Convert 35°C to °F

$$\begin{aligned}\text{Temperature, °F} &= 9/5\,(\text{°C}) + 32\text{°F}\\ &= 9/5\,(35\text{°C}) + 32\text{°F}\\ &= 63 + 32\\ &= 95\text{°F}\end{aligned}$$

7.02 Chemical Names and Formulas

In the laboratory, chemical symbols are used as "shorthand" for the names of the elements. The names and symbols for some of these elements are listed below.

Chemical Name	Symbol
Calcium	Ca
Carbon	C
Chlorine	Cl
Copper	Cu
Fluorine	F
Hydrogen	H
Iron	Fe
Magnesium	Mg
Manganese	Mn
Nitrogen	N
Oxygen	O
Sodium	Na
Sulfur	S

C
Ca
H
Cl
F
Cu
O
Na
Fe

A compound is a pure substance composed of two or more different elements and whose composition (proportion of elements) is constant. Generally, all chemical compounds can be divided into two main groups, organic and inorganic. Organic compounds are those which contain the element carbon (C). There are, however, a few simple substances containing carbon which are considered to belong to the realm of inorganic chemistry. These include carbon dioxide (CO_2), carbon monoxide (CO), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) as in calcium carbonate ($CaCO_3$).

Many different compounds can be made from the same two or three elements. Therefore, you must carefully read the formula and name to prevent errors and accidents. A chemical formula is a "shorthand" or abbreviated way to write the name of a chemical compound. For example, the name sodium chloride (common table salt) can be written "NaCl." Table 7.1 lists commonly used chemical compounds found in the water laboratory.

TABLE 7.1 NAMES AND FORMULAS OF CHEMICALS COMMONLY USED IN WATER ANALYSES

Chemical Name	Chemical Formula
Acetic Acid	CH_3COOH
Aluminum Sulfate (alum)	$Al_2(SO_4)_3 \cdot 14.3\ H_2O^a$
Ammonium Hydroxide	NH_4OH
Calcium Carbonate	$CaCO_3$
Chloroform	$CHCl_3$
Copper Sulfate	$CuSO_4$
Ferric Chloride	$FeCl_3$
Nitric Acid	HNO_3
Phenylarsine Oxide	C_6H_5AsO
Potassium Iodide	KI
Sodium Bicarbonate	$NaHCO_3$
Sodium Hydroxide	NaOH
Sulfuric Acid	H_2SO_4

[a] 14.3 H_2O. Alum in the dry form based on 17% Al_2O_3.

Poor results and safety hazards are often caused by using a chemical from the shelf that is *NOT* exactly the same chemical called for in a particular procedure. The mistake usually occurs when the chemicals have similar names or formulas. This problem can be eliminated if you use *BOTH* the chemical name and formula as a double check. The spellings of many chemical names are quite similar. These slight differences are critical because the chemicals do not behave alike. For example, the chemicals potassium nitr*A*te (KNO_3) and potassium nitr*I*te (KNO_2) are just as different in meaning chemically as the words f*A*t and f*I*t are to your doctor.

7.03 Helpful References

1. *METHODS FOR CHEMICAL ANALYSIS OF WATER AND WASTES*, EPA 600/4-79-020, Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 26 W. St. Clair Street, Cincinnati, Ohio 45268.
2. *SIMPLIFIED PROCEDURES FOR WATER EXAMINATION-M12*, 1978, Order 30012. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to members, $19.00; nonmembers, $23.50.
3. *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER*, 16th Edition, 1985. Order NO. 10019. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to members, $72.00; nonmembers, $90.00.
4. *HANDBOOK FOR ANALYTICAL QUALITY CONTROL IN WATER AND WASTEWATER LABORATORIES*, EPA 600/4-79-019, Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 26 W. St. Clair Street, Cincinnati, Ohio 45268.

5. *MICROBIOLOGICAL METHODS FOR MONITORING THE ENVIRONMENT*, U.S. Environmental Protection Agency, December 1978. Available through the National Technical Information Service, Springfield, Virginia 22161. Order No. EPA-600/8-78-017, Price $26.00.
6. *INTRODUCTION TO WATER QUALITY ANALYSIS*, Volume 4, Order No. 1931. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price, $14.00.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 402.

7.0A Why are laboratory control tests important?

7.0B What does the prefix milli- mean?

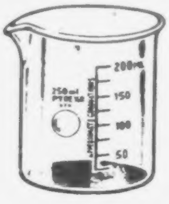
7.0C What's the proper name of the chemical compound, $CaCO_3$?

7.1 LABORATORY EQUIPMENT AND TECHNIQUES

7.10 Water Laboratory Equipment

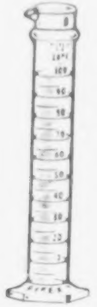
The items of equipment in a water laboratory are the operator's "tools-of-the-trade." In any laboratory there are certain basic pieces of equipment that are used routinely to perform tests such as those used in water analysis. The following is a brief description of several of the more common items of glassware and pieces of equipment used in the analysis of water.

BEAKERS. Beakers are the most common pieces of laboratory equipment. They come in sizes from 1 m*L* to 4000 m*L*. They are used mainly for mixing chemicals and to measure approximate volumes.



Beaker

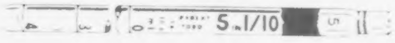
GRADUATED CYLINDERS. Graduated cylinders also are basic to any laboratory and come in sizes from 5 m*L* to 4000 m*L*. They are used to measure volumes more accurately than beakers.



Cylinder, Graduated

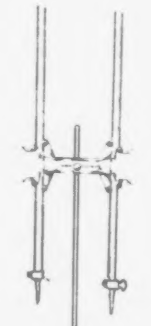
PIPETS. Pipets are used to deliver accurate volumes and range in size from 0.1 m*L* to 100 m*L*.

Pipet
(PIE-pet)
Volumetric

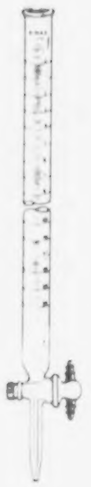


Pipet, Serological

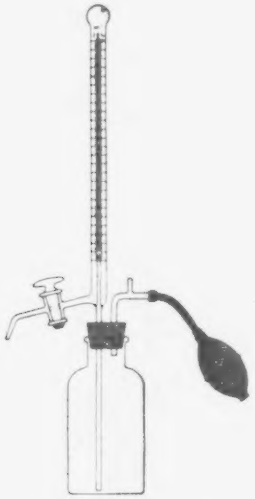
BURETS. Burets are also used to deliver accurate volumes. They are especially useful in a procedure called "titration." Burets come in sizes from 10 to 1000 m*L*.



Support, Buret & Buret Clamp

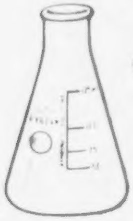


Buret
(bur-RET)

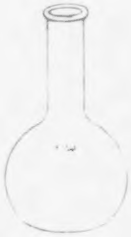


Automatic
Buret

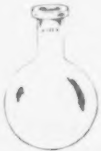
FLASKS. Flasks are used for containing and mixing chemicals. There are many different sizes and shapes.



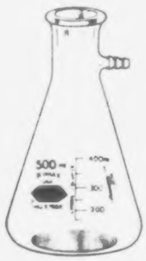
Flask,
Erlenmeyer
(ER-len-MY-er)
Wide Mouth



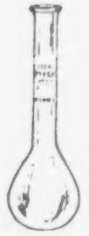
Flask,
Boiling
Flat Bottom



Flask,
Boiling
Round Bottom
Short Neck



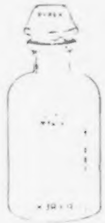
Flask,
Filtering



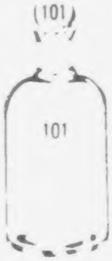
Kjeldahl Flask
(Kell-doll)

Flask,
Distilling

BOTTLES. Bottles are used to store chemicals, to collect samples for testing purposes, and to dispense liquids.

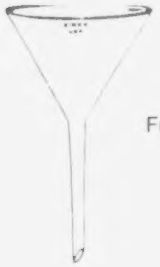


Bottle,
Reagent



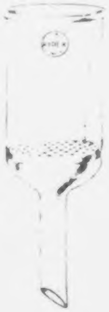
Bottle,
BOD

FUNNELS. A funnel is used for pouring solutions or transferring solid chemicals. This funnel also can be used with filter paper to remove solids from a solution.



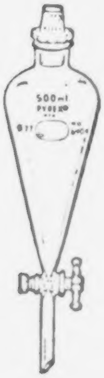
Funnel

A Buchner funnel is used to separate solids from a mixture. It is used with a filter flask and a vacuum.



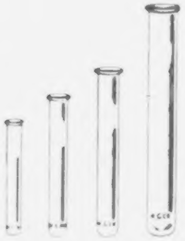
Funnel,
Buchner
With
Perforated Plate

Separatory funnels are used to separate one chemical mixture from another. The separated chemical usually is dissolved in one or two layers of liquid.

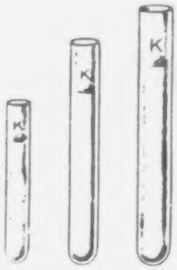

500 ml
PYREX

Separatory Funnel

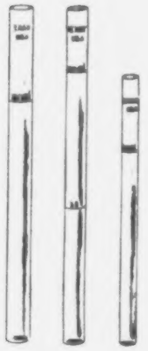
TUBES. Test tubes are used for mixing small quantities of chemicals. They are also used as containers for bacterial testing (culture tubes).



Test Tube

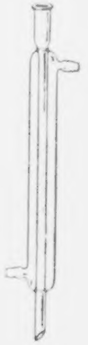


Culture Tube
Without Lip

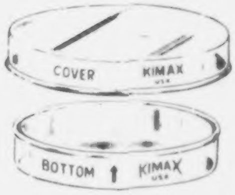


Color Comparison
Tubes, Nessler

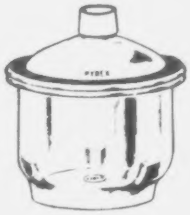
OTHER LABWARE AND EQUIPMENT.



Condenser

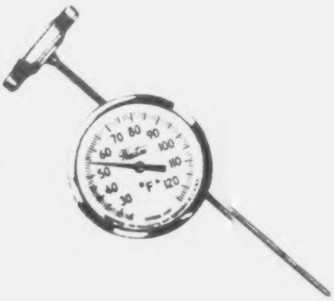

COVER
KIMAX
BOTTOM
KIMAX

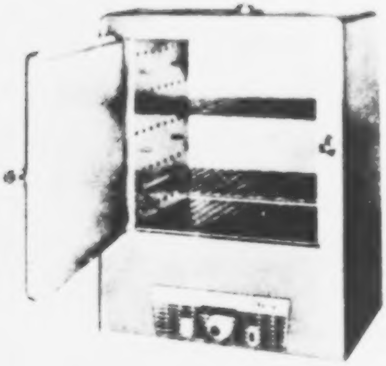
Dish, Petri



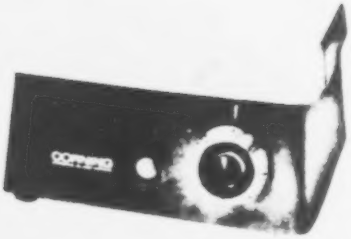
Desiccator
(DESS-uh-KAY-tor)

Thermometer, Dial

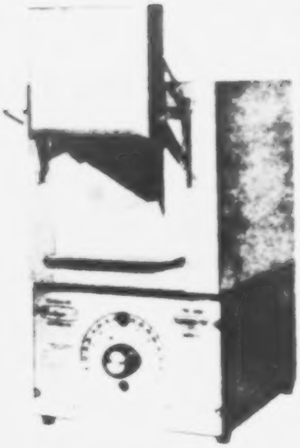

30
40
50
60
70
80
90
100
110
120
°F°



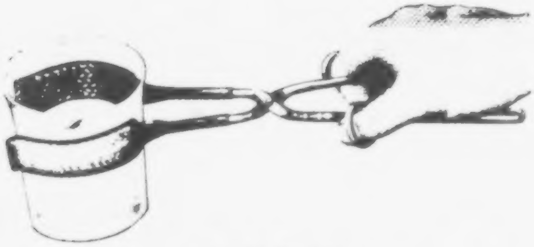
Oven, Mechanical Convection



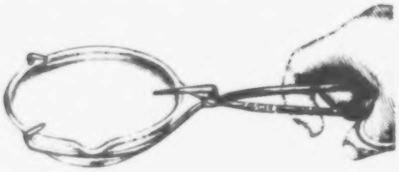
Hot Plate



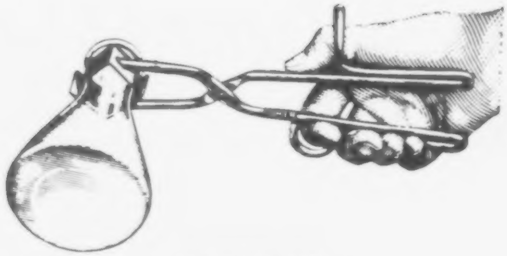
Muffle Furnace, Electric



Clamp, Beaker, Safety Tongs

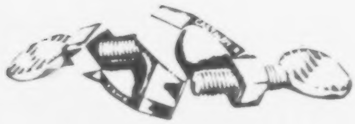


Clamp, Dish, Safety Tongs

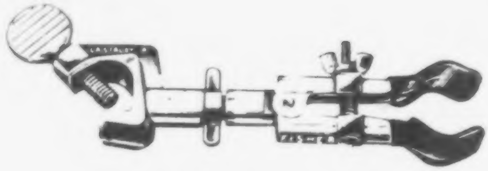


Clamp, Flask, Safety Tongs

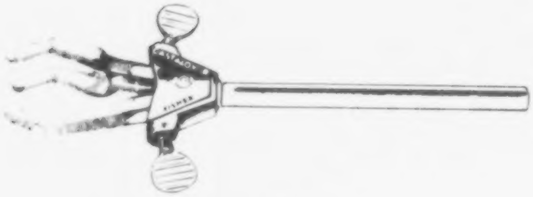
Clamp, Test Tube



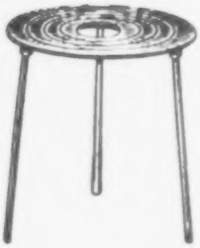
Clamp Holder



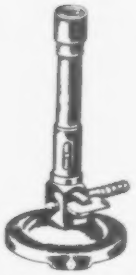
Clamp, Utility



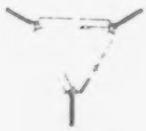
Clamp



Tripod, Concentric Ring



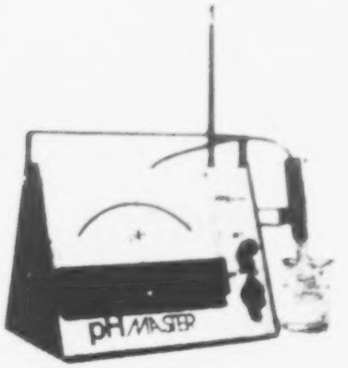
Burner, Bunsen



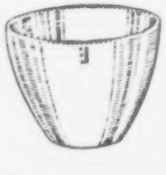
Triangle, Fused

Fume Hood

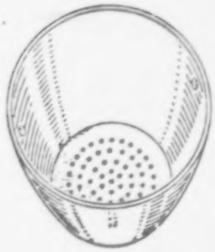
Dissolved Oxygen Meter



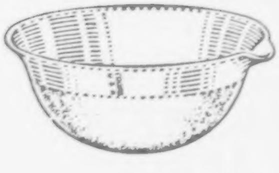
pH Meter



Crucible, (CREW-suh-bull),
Porcelain



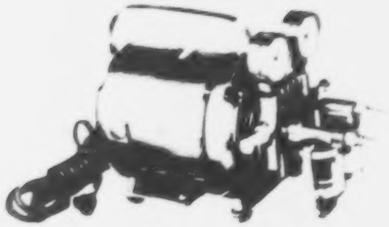
Crucible,
Gooch
(GOO-ch)
Porcelain



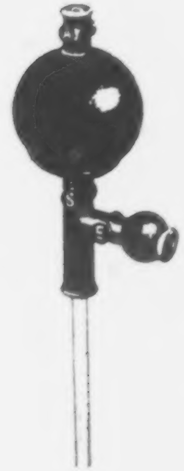
Dish,
Evaporating

pHydrion
Papers B
DOUBLE ROLL
pH1 3 5 7 9 11

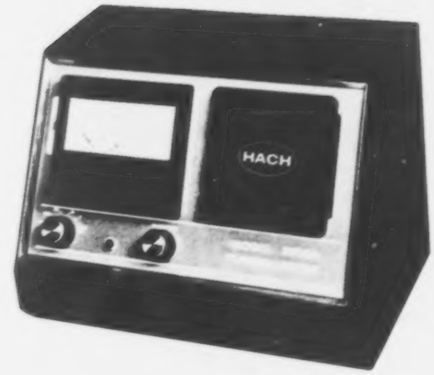
Test Paper, pH 1-11



Pump, Air Pressure & Vacuum



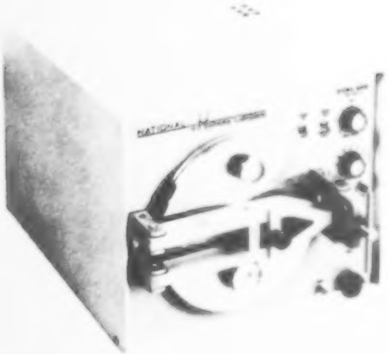
Pipet Bulb



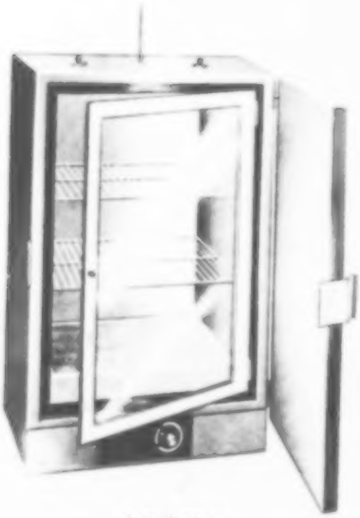
Turbidimeter
Permission of Hach Company

Ratio turbidimeter
(Permission of Hach Company)

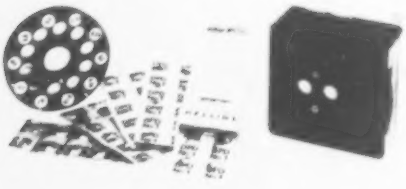
Magnetic stirrer
(Permission of Thermolyne)



Autoclave
(Permission of Napco)



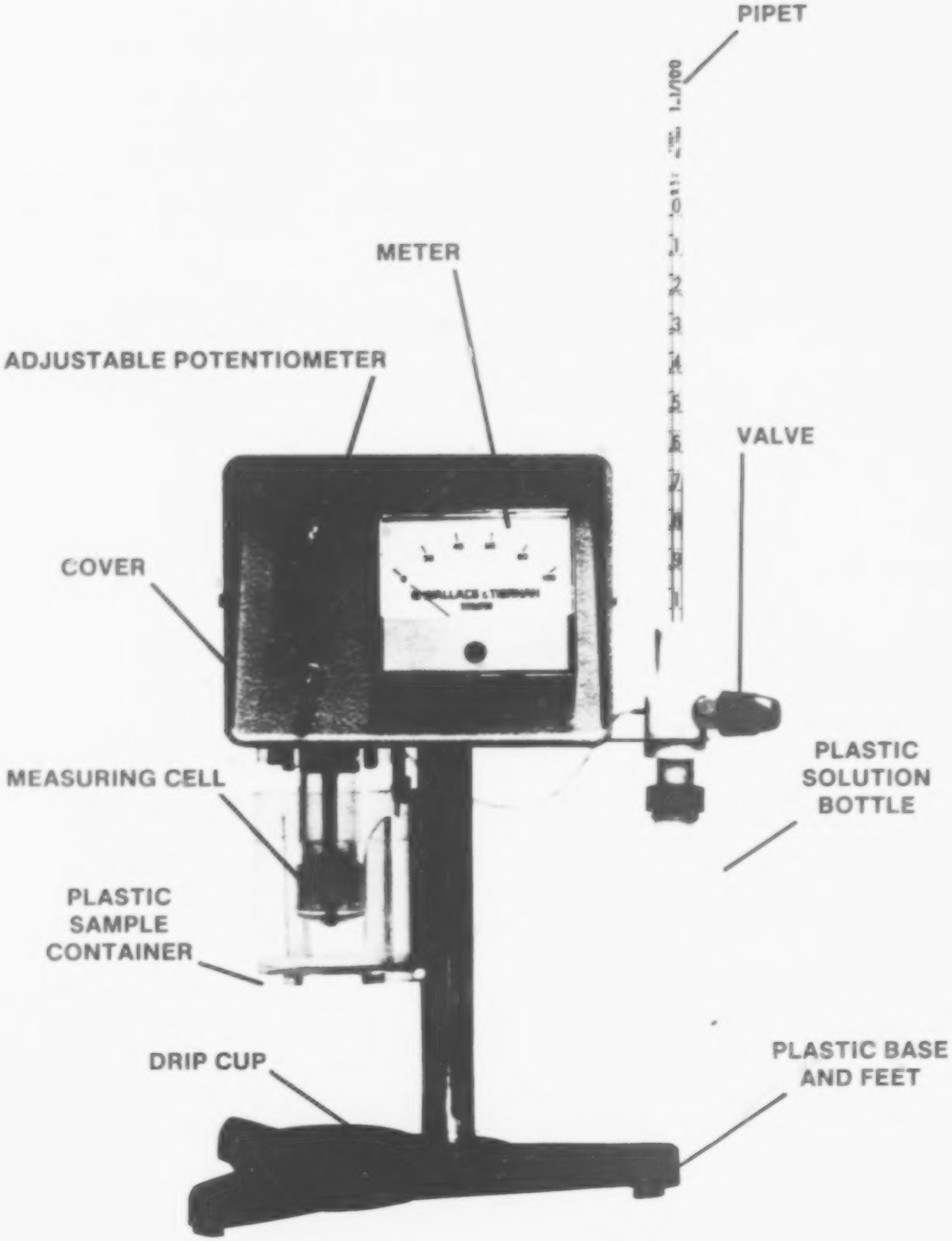
Incubator
(Permission of Blue M Electric)



Color comparator
(Permission of Hellige Co.)

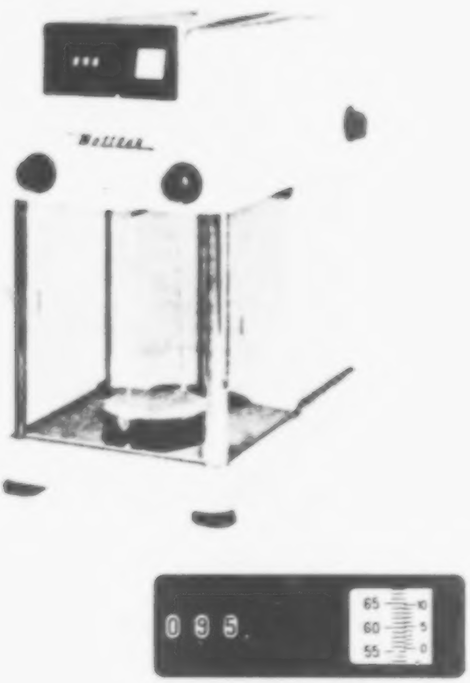
HACH
dr/2 spectrophotometer

Spectrophotometer
(Permission of Hach)


PIPET
1.1/100
METER
ADJUSTABLE POTENTIOMETER
VALVE
COVER
WALLACE & TIERNAN
PLASTIC SOLUTION BOTTLE
MEASURING CELL
PLASTIC SAMPLE CONTAINER
DRIP CUP
PLASTIC BASE AND FEET

Amperometric titrator

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)



Weight = 95.5580 gm.

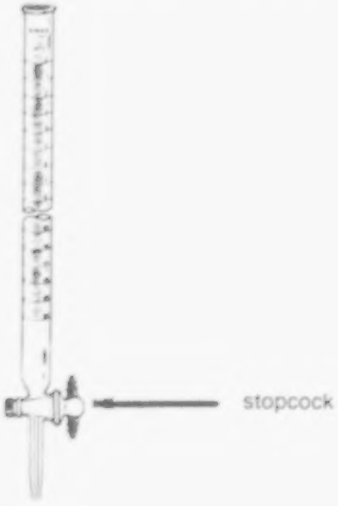
Balance, Analytical

(Permission of Mettler)

7.11 Use of Laboratory Glassware

BURETS

A buret is used to give accurate measurements of liquid volumes. The stopcock controls the amount of liquid which will flow from the buret. A glass stopcock must be lubricated (stopcock grease) and should not be used with alkaline solutions. A teflon stopcock never needs to be lubricated.



BURET

Burets come in several sizes, with those holding 10 to 25 milliliters used most frequently.

When a buret is filled with liquid, the surface of the liquid is curved. This curve of the surface is called the meniscus (me-NIS-cuss). Depending on the liquid, the curve may be up, as with mercury, or down as with water. Since most solutions used in the laboratory are water-based, always read the bottom of the meniscus with your eye at the same level (Fig. 7.1). If you have the meniscus at eye level, the closest marks that go all the way around the buret will appear as straight lines, not circles.

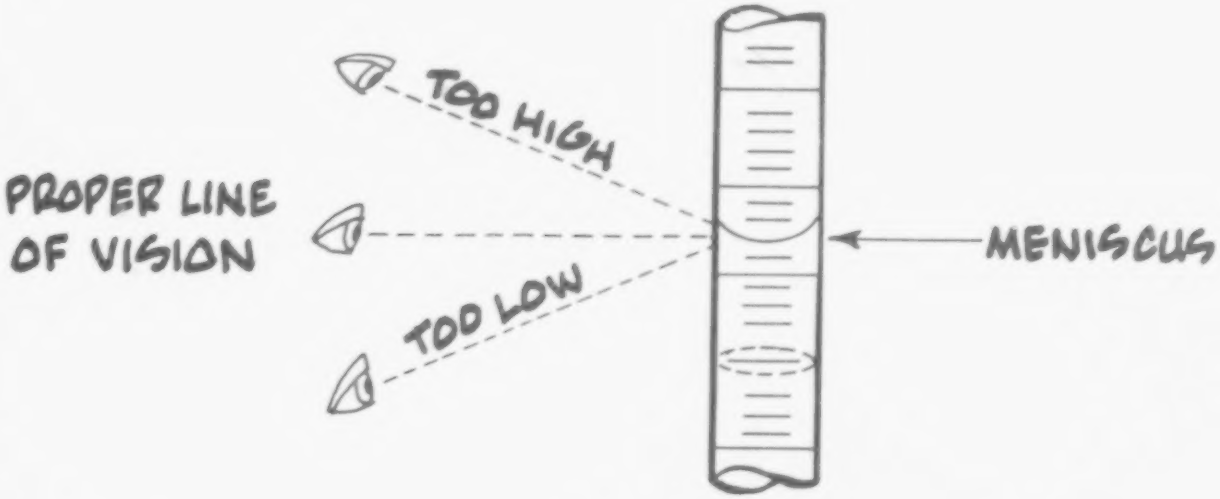
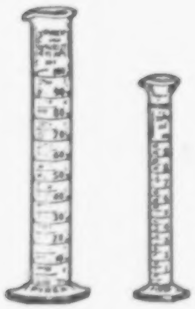


Fig 7.1 How to read meniscus

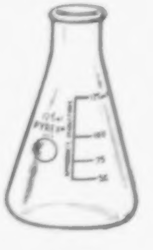


GRADUATED CYLINDERS

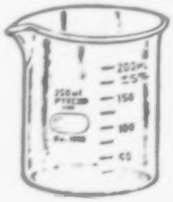
The graduated cylinder or "graduate" is one of the most often used pieces of laboratory equipment. This cylinder is made either of glass or of plastic and ranges in sizes from 10 m*L* to 4 liters. The graduate is used to measure volumes of liquid with an accuracy *LESS* than burets but *GREATER* than beakers or flasks. Graduated cylinders should never be heated in an open flame because they will break.

FLASKS AND BEAKERS

Beakers and flasks are used for mixing, heating, and weighing chemicals. Most beakers and flasks are *NOT* calibrated with exact volume lines; however, they are sometimes marked with approximate volumes and can be used to estimate volumes.



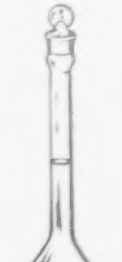
Flask



Beaker

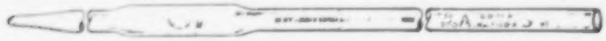
VOLUMETRIC FLASKS

Volumetric flasks are used to prepare solutions and come in sizes from 10 to 2000 m*L*. Volumetric flasks should *NEVER* be heated. Rather than store liquid chemicals in volumetric flasks, the chemicals should be transferred to a storage bottle.

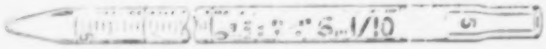


PIPETS

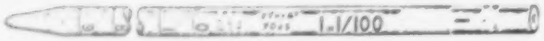
Pipets are used for accurate volume measurements and transfer. There are three types of pipets commonly used in the laboratory — volumetric pipets, graduated or Mohr pipets, and serological pipets.



Volumetric Pipet



Graduated Pipet



Serological Pipet

Volumetric pipets are available in sizes such as 1, 10, 25, 50, and 100 m*L*. They are used to deliver a single volume. Measuring and serological pipets, however, will deliver fractions of the total volume indicated on the pipet.

In emptying volumetric pipets, they should be held in a vertical position and the outflow should be unrestricted. The tip should be touched to the wet surface of the receiving vessel and kept in contact with it until the emptying is complete. Under no circumstance should the small amount remaining in the tip be blown out.

Measuring and serological pipets should be held in the vertical position. After outflow has stopped, the tip should be touched to the wet surface of the receiving vessel. No drainage period is allowed. Where the small amount remaining in the tip is to be blown out and added, this will be indicated by a frosted band near the top of the pipet.

Use of a pipet filter or pipet bulb (page 351) is recommended to draw the sample into a pipet. Never pipet chemical reagent solutions or unknown water samples by mouth. Use the following techniques for best results.

1. Draw liquid up into the pipet past the calibration mark.
2. Quickly remove the bulb and place dry finger tip over the end of the pipet.
3. Wipe excess liquid from the tip of the pipet using laboratory tissue paper.
4. Lift finger and allow desired amount, or all, of liquid to drain.

ACKNOWLEDGMENTS.

Pictures of laboratory glassware and equipment in the manual are reproduced with the permission of VWR Scientific, San Francisco, California, with exceptions noted.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 402.

7.1A For each type of glassware listed below, describe the item and its use or purpose.

1. Beaker
2. Graduated cylinders
3. Pipets
4. Burets

7.1B Why should graduated cylinders never be heated in an open flame?

7.1C What is a meniscus?

7.12 Chemical Solutions

Many laboratory procedures do not give the concentrations of standard solutions in grams/liter or milligrams/liter. Instead, the concentrations are usually given as *NORMALITY (N)*,[1] which is the standard designation for solution strengths in chemistry.

EXAMPLES:

$0.025\ N\ H_2SO_4$ means a 0.025 normal solution of sulfuric acid

2 *N* NaOH means that the normality of a sodium hydroxide solution is 2

The LARGER the number in front of the *N*, the MORE concentrated the solution. For example, 1 *N* NaOH solution is more concentrated than a 0.2 *N* NaOH solution.

Another method of specifying the concentration of solutions uses the "a + b system." This means that "a" volumes of concentrated reagent are diluted with "b" volumes of distilled water to form the required solution.

EXAMPLES:

1 + 1 HCl means 1 volume of concentrated HCl is diluted with 1 volume of distilled water

$1 + 5\ H_2SO_4$ means 1 volume of concentrated sulfuric acid is diluted with 5 volumes of distilled water

When the exact concentration of a prepared chemical solution is known, it is referred to as a "standard solution." Many times standard solutions can be ordered already prepared from chemical supply companies. Once a standard has been prepared, it can then be used to standardize other laboratory solutions. To standardize a solution means to determine and adjust its concentration accurately, thereby making it a standard solution. "Standardization" is the process of using one solution of known concentration to determine the concentration of another solution. This action often involves a procedure called a "titration."

When preparing standard solutions or reagents, the directions may say to weigh out 7.6992 grams of a chemical and dilute to one liter with distilled water. To weigh out 7.6992 grams of a chemical, determine the weight of a weighing dish and add this weight to the weight of the chemical. Place the weighing dish on the weighing platform of an analytical balance. (See page 474. Some balances have the weighing platform on top for the weighing dish.) Gently add the chemical to the weighing dish until you are slightly below the desired weight. The weighing mechanism should be off while the chemical is being added and then turned on to determine the exact weight. When you get close to the exact weight, place some of the chemical on a spatula. Gently tap the spatula to add very small amounts of chemical to the weighing dish. Continue this procedure until you've reached the exact weight. If you add too much chemical, remove some of the chemical with the spatula and again repeat the procedure until you reach the exact weight.

Another procedure is to place approximately the desired weight in the weighing dish. Weigh this amount exactly. Then add a proportionate amount of distilled water.

EXAMPLE 1

The directions for preparing a standard reagent indicate that you should weigh out 7.6992 grams and dilute to one liter. You weigh out 7.5371 grams. How much water should be added to produce the desired concentration or normality of the standard reagent?

KNOWN	UNKNOWN
Desired Weight, gm = 7.6992 gm	Water, m*L*
Actual Weight, gm = 7.5371 gm	

The chemical should be diluted to how many milliliters?

$$\text{Dilute to m}L = \frac{(\text{Actual Weight, gm})(1000\text{ m}L)}{(\text{Desired Weight, gm})}$$

$$= \frac{(7.5371\text{ gm})(1000\text{ m}L)}{(7.6992\text{ gm})}$$

$$= 979\text{ m}L$$

The 7.5371 grams of chemical should be diluted to 979 m*L*.

7.13 Titrations

A titration involves the measured addition of a standardized solution, which is generally in a buret, to another solution in a flask or beaker. The solution in the buret, is referred to as the "titrant" and is added to the other solution until there is a measurable change in the test solution in the flask or beaker. This change is frequently a color change as a result of the addition of another chemical called an "indicator" to the solution in the flask before the titration begins. The solution in the buret is added slowly to the flask until the change, which is called the "end point," is reached. The entire process is the "titration." Figure 7.2 illustrates the four general steps used during a chemical titration.

---

[1] *Normal. A normal solution contains one gram equivalent weight of a reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A 1 N solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.*

7.14 Data Recording and Recordkeeping

The use of a laboratory notebook and worksheets are a must for laboratory analysts, water supply system and treatment plant operators. Notebooks and worksheets help you record data in an orderly manner. Too often, hours of work are wasted when test results and other data (such as a sample volume) are written down on a scrap of paper only to be misplaced or thrown away by mistake. Notebooks and worksheets help prevent error and provide a record of your work. The routine use of laboratory worksheets and notebooks is the only way an operator or a lab person can be sure that all important information is properly recorded.

There is no standard laboratory form. Most operators usually develop their own data sheets for recording test results and other important data. These data sheets should be prepared in a manner that makes it easy for you to record results, review them, and recover these results when it is necessary. Each treatment plant will have different needs for collecting and recording data and may require several different data or worksheets. Figure 7.3 and 7.4 and illustrate two typical laboratory worksheets.

7.15 Laboratory Quality Control

Having good equipment and using the correct methods are not enough to insure correct analytical results. Each operator must be constantly alert to factors in the water treatment process which can lead to poor quality of data. Such factors include sloppy laboratory technique, deteriorated reagents and standards, poorly operating instruments, and calculation mistakes. One of the best ways to insure quality control in your laboratory is to analyze reference-type samples to provide independent checks on your analysis. These reference-type samples are available from the U.S. Environmental Protection Agency and from commercial sources. From time to time, it is also a good idea to split a sample with one of your fellow operators or another laboratory and compare analytical results. In addition, frequent self-appraisal and evaluation — from sampling to reporting results — can help you gain full confidence in your results.

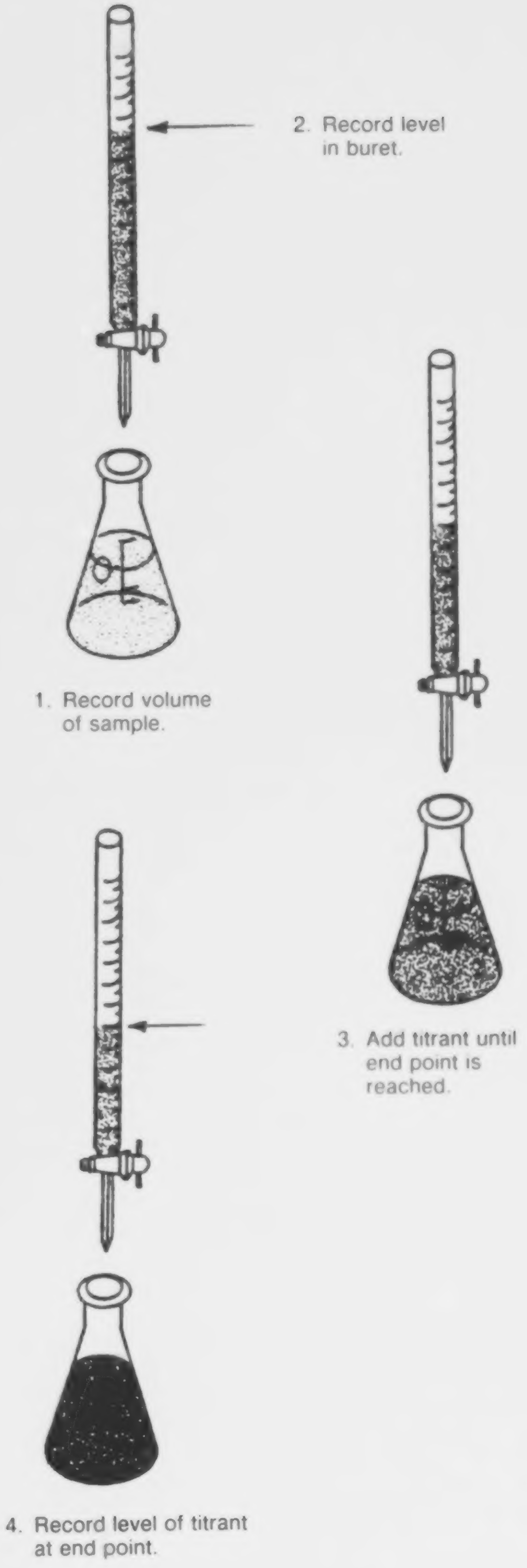
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 402.

7.1D What is a "standard solution?"

7.1E What is the primary purpose of laboratory notebooks and worksheets?

7.1F List three sources or causes of poor quality of analytical data.



2. Record level in buret.
1. Record volume of sample.
3. Add titrant until end point is reached.
4. Record level of titrant at end point.

Fig. 7.2 Titration steps

WATER ANALYSES REPORT SHEET

(All results in mg/L except as noted)

SAMPLE SOURCE:			
DATE SAMPLED:	BY:		
ANALYST:	DATE COMPLETED:		
A. PHYSICAL PARAMETERS	METHODS INDEX		
color (units)	Std. Methods pg. 67		
odor (units)	Std. Methods pg. 85		
turbidity (NTU)	Std. Methods pg. 131		
B. GENERAL MINERAL	METHODS INDEX		
pH (units)	Std. Methods pg. 429		
total alkalinity ($CaCO_3$)	Std. Methods pg. 269		
Specific conductance μmhos/cm	Std. Methods pg. 76		
total dissolved residue	Std. Methods pg. 95		
total hardness ($CaCO_3$)	Std. Methods pg. 209		
calcium	Std. Methods pg. 196		
magnesium	Std. Methods pg. 226		
iron	Std. Methods pg. 214		
manganese	Std. Methods pg. 228		
chloride	Std. Methods pg. 286		
sulfate	Std. Methods pg. 464		

Fig. 7.3 Typical laboratory worksheet

7.16 Laboratory Safety

Safety is just as important in the laboratory as it is outside the lab. State laws and the Occupational Safety and Health Act (OSHA) demand that proper safety procedures be exercised in the laboratory at all times. OSHA specifically deals with "safety at the place of work." The Act requires that "each employer has the general duty to furnish all employees with employment free from recognized hazards causing, or likely to cause, death or serious physical harm."

Personnel working in the water industry must realize that a number of hazardous materials and conditions can exist. Always be alert and careful. Be aware of potential dangers at all times. Safe practice in the laboratory and anytime while working around chemicals requires hardly any more effort than unsafe practices, with the important benefits from prevention of injury to you and your fellow operators.

On specific questions of safety, consult your state's General Industrial Safety Orders or OSHA regulations.

7.160 Laboratory Hazards

Working with chemicals and other materials in the water laboratory can be dangerous. Laboratory hazards include:

1. Hazardous materials,
2. Explosions,
3. Cuts and bruises,
4. Electrical shock,
5. Fire, and
6. Burns (heat and chemical).

Sheet No. ____________
Day ____________
Date ____________

AMERICAN RIVER
WATER TREATMENT PLANT

WATER QUALITY

Washwater used M.G.	
Gals. Alum used	
Lbs. Cl_2 used	
Lbs. Lime used	

Time	Turbidity		Hydrogen Ion Conc.(pH)			Alkalinity			Cl_2 Residual			Chlorine		Chemical Dose			TEMP. °C	
											TAP	Chlorine						
	RAW	Filter Effluent	RAW	Res. Influent	TAP Res.	RAW T-Alk	TAP T-Alk	TAP P-alk	Pre-Chlor	Res. Influent	Res	Pre	Post	Alum	Lime		Raw ╱ Tap	
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Fig. 7.4 Typical operational worksheet

388

Hazardous materials include (1) corrosive, (2) toxic, and (3) explosive or flammable materials.

1. Corrosive Materials

   ACIDS

   a. Examples: Hydrochloric or muriatic (HCl), hydrofluoric (HF), glacial acetic (CH_3COOH), nitric (NHO_3), and sulfuric (H_2SO_4).

   b. Acids can be extremely corrosive and hazardous to human tissue, metals, clothing, cement, stone, and concrete.

   c. Commercially available spill clean-up kits should be kept on hand to neutralize the acid in the event of an accidental spill. Baking soda (bicarbonate, *NOT* laundry soda) effectively neutralizes acids. Baking soda can be used on lab and human surfaces without worrying about toxicity.

   BASES (Caustics)

   a. Examples: Sodium hydroxide (caustic soda or lye, NaOH), quick lime (CaO), hydrated lime ($Ca(OH)_2$), and alkaline iodine-azide solution (used in dissolved oxygen test).

   b. Bases are extremely corrosive to skin, clothing, and leather.

   c. Commercially available spill clean-up materials should be kept on hand for use in the event of an accidental spill. A jug of cheap vinegar can be kept on hand to neutralize bases and will not harm your skin.

   MISCELLANEOUS CHEMICALS

   a. Examples: Alum, chlorine, ferric salts (ferric chloride), and other strong oxidants.

2. Toxic Materials

   Examples:

   a. Solids: Cyanide compounds, chromium, orthotolidine, cadmium, mercury, and other heavy metals.

   b. Liquids: Chloroform and other organic solvents.

   c. Gases: Chlorine, ammonia, sulfur dioxide, and chlorine dioxide.

3. Explosive or Flammable Materials

   Examples:

   a. Liquids: Acetone, ethers, and gasoline.

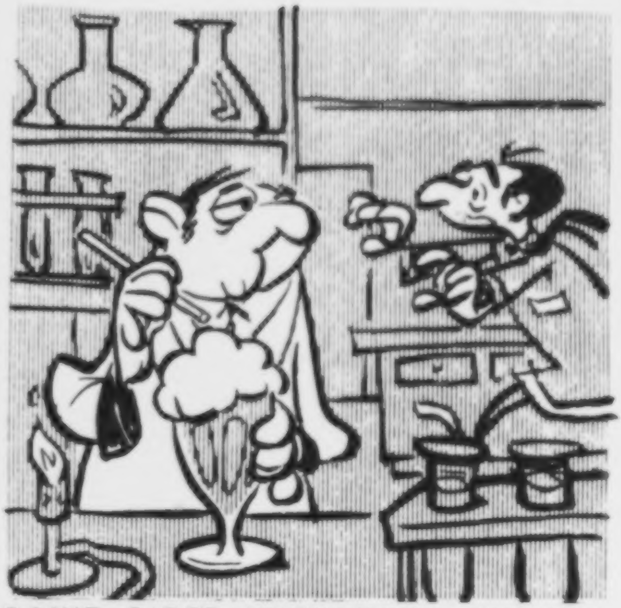
   b. Gases: Propane and hydrogen.

7.161 Personal Safety and Hygiene

Laboratory work can be quite dangerous if proper precautions and techniques are not taken. *ALWAYS* follow these basic rules:

1. *NEVER* work all alone in the laboratory. Someone should always be available to help in case you should have an accident which blinds you, leaves you unconscious, or starts a fire you can't handle. If necessary have someone check on you regularly to be sure you are OK.
2. Wear protective goggles or eye glasses at all times in the laboratory. Contact lenses should not be worn, even under safety goggles, because fumes can seep between the lens and the eyeball and irritate the eye.
3. Never pipet hazardous materials by your mouth.

Safety Glasses



DON'T PIPET HAZARDOUS LIQUIDS BY MOUTH.

4. Always wear a lab coat or apron in the laboratory to protect your skin and clothes.
5. Wear asbestos gloves when handling hot objects. If there is a danger of hot liquid erupting from a container, wear a face shield, too.
6. Don't keep food in a refrigerator that is used for chemical and/or sample storage.
7. Good housekeeping is an effective way to prevent accidents.

7.162 Prevention of Laboratory Accidents

7.1620 Chemical Storage An adequate chemical storeroom is essential for safety in the water laboratory. The storeroom should be properly ventilated and lighted and be laid out to segregate incompatible chemicals. Order and cleanliness must be maintained. Clearly label and date all chemicals and bottles or reagents.

Store heavy items on or as near to the floor as possible. *VOLATILE LIQUIDS*[2] which may escape as a gas, such as ether, must be kept away from heat sources, sunlight, and electrical switches.

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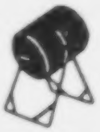
[2] *Volatile Liquids (VOL-uh-tull). Liquids which easily vaporize or evaporate at room temperature.*

CLAMPS, RAISED SHELF EDGES AND PROPER ARRANGEMENT PREVENT STOCKROOM FALLOUT.

Cap and secure cylinders of gas in storage to prevent rolling or tipping. They should also be placed away from any possible sources of heat or open flames.

Follow usual common sense rules of storage. Good housekeeping is a most significant contribution toward an active safety campaign.

7.1621 Movement of chemicals. The next area of concern is the transfer of chemicals, apparatus, gases, or other hazardous materials from the storeroom to the laboratory for use. Use cradles or tilters to facilitate handling, carboys or other larger chemical vessels.



Drum Tilter

In transporting cylinders of compressed gases, use a trussed handtruck. Never roll a cylinder by its valve. Immediately after they are positioned for use, cylinders should be clamped securely into place to prevent shifting or toppling.

Carry flammable liquids in safety cans or, in the case of reagent-grade chemicals, protect the bottle with a carrier. Always wear protective gloves, safety shoes, and rubber aprons in case of accidental spilling of chemical containers.

7.1622 Proper laboratory techniques. Faulty technique is one of the chief causes of accidents and, because it involves the human element, is one of the most difficult to correct.

Because of their nature and prevalence in the laboratory, acids and other corrosive materials constitute a series of hazards ranging from poisoning, burning, and gassing through explosion. Always flush the outsides of acid bottles with water before opening them. Don't lay the stopper down on the counter top where a person might lay a hand or rest an arm on it. Keep all acids tightly stoppered when not in use and make sure no spilled acid remains on the floor, table, or bottle after use. To avoid splashing of acid, don't pour water into acid; ALWAYS POUR ACID INTO WATER.

Mercury requires special care. Even a small amount in the bottom of a drawer can poison the atmosphere in a room. After an accident involving mercury, go over the entire area carefully until there are no globules remaining. Keep all mercury containers well-stoppered.

7.1623 Accident prevention *ELECTRICAL SHOCK*. Wherever there are electrical outlets, plugs, and wiring connections, there is a danger of electrical shock. The usual "do's" and "don'ts" of protection against shock in the home are equally applicable in the laboratory. Don't use worn or frayed wires. Replace connections when there is any sign of thinning insulation. Ground all apparatus using three-prong plugs. Don't continue to run a motor after liquid has spilled on it. Turn it off immediately and clean and dry the inside thoroughly before attempting to use it again.

Electrical units which are operated in an area exposed to flammable vapors should be explosion proof. All permanent wiring should be installed by an electrician with proper conduit or BX cable to eliminate any danger of circuit overloading.

CUTS. Some of the pieces of glass used in the laboratory, such as glass tubing, thermometers, and funnels, must be inserted through rubber stoppers. If the glass is forced through the hole in the stopper by applying a lot of pressure, the glass usually breaks. This is one of the most common sources of cuts in the laboratory.

Use care in making rubber-to-glass connections. Lengths of glass tubing should be supported while they are being inserted into rubber. The ends of the glass should be *FLAME POLISHED*[3] and either wetted or covered with a lubricating jelly for ease in joining connections. Never use oil or grease. Wear gloves when making such connections, and hold the tubing as close to the end being inserted as possible to prevent bending or breaking.

Never try to force rubber tubing or stoppers from glassware. Cut off the rubber or materials.

A FIRST-AID kit must be available in the laboratory.

BURNS. All glassware and porcelain look cold after the red from heating has disappeared. The red is gone in seconds but the glass is hot enough to burn for several minutes. After heating a piece of glass, put it out of the way until cold.

Spattering from acids, caustic materials, and strong oxidizing solutions should be washed off immediately with large quantities of water. Every worker in the water laboratory should have access to a sink and an emergency deluge shower. Keep vinegar and soda handy to neutralize acids and bases (caustic materials).

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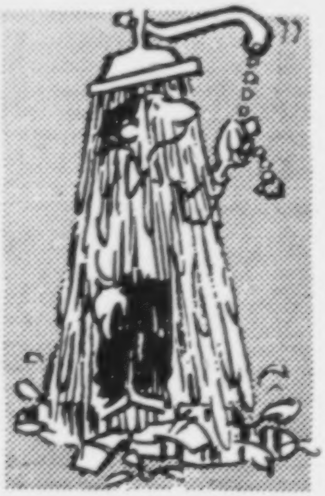
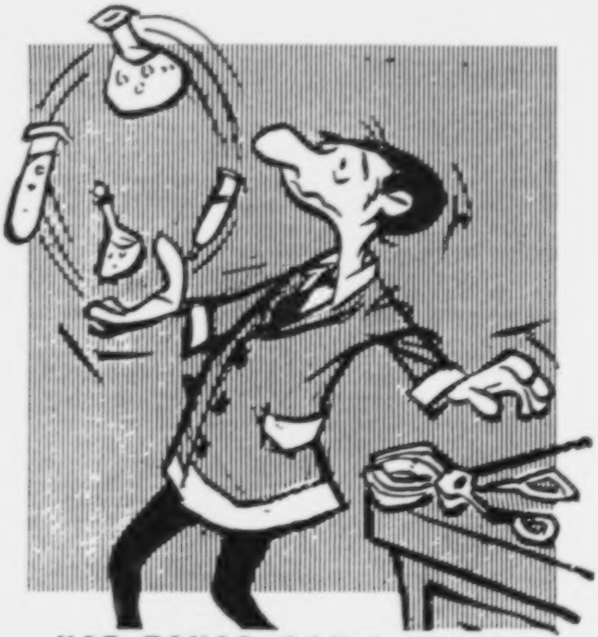
[3] *Flame Polished. Melted by a flame to smooth out irregularities. Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.*



Many safeguards against burns are available. Gloves, safety tongs, aprons, and emergency deluge showers are but a few examples. Never decide it is too much trouble to put on a pair of gloves or use a pair of tongs to handle a dish or flask that has been heated.



USE TONGS—DON'T JUGGLE HOT CONTAINERS.

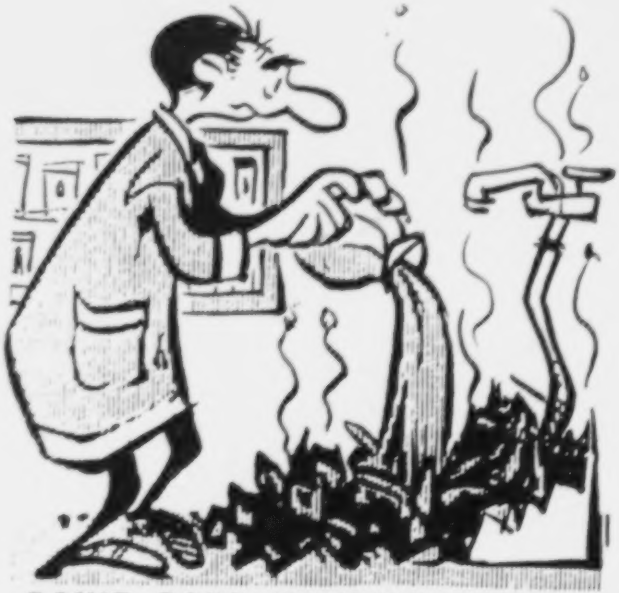
Perhaps the most harmful and painful chemical burn occurs when small objects, chemicals or fumes get into your eyes. Immediately flood your eyes with water or a special "eye wash" solution from a safety kit or from an eyewash station or fountain.

TOXIC FUMES. Use a fumehood for routine reagent preparation. Pick a hood that has adequate air displacement and expels harmful vapors and gases at their source. An annual check should be made of the entire laboratory building. Sometimes noxious fumes are spread by the heating and cooling system of the building.

When working with chlorine and other toxic substances, always wear a self-contained breathing apparatus. If possible, try to clear the atmosphere with adequate ventilation *BEFORE* entry.

WASTE DISPOSAL. A good safety program requires constant care in disposal of laboratory waste. Corrosive materials should never be poured down a sink or drain. These substances can corrode away the drain pipe and/or trap. Corrosive acids should be poured down corrosion-resistant sinks and sewers using large quantities of water to dilute and flush the acid.

To protect maintenance personnel, use separate covered containers to dispose of broken glass.



DON'T POUR VOLATILE LIQUIDS INTO THE SINK.

FIRE. The laboratory should be equipped with a fire blanket. The fire blanket is used to smother clothing fires. Small fires which occur in an evaporating dish or beaker may be put out by covering the container with a glass plate, wet towel, or wet blanket. For larger fires, or ones which may spread rapidly, promptly use a fire extinguisher. Do not use a fire extinguisher on small beaker fires because the force of the spray will knock over the beaker and spread the fire. Take time to become familiar with the operation and use of your fire extinguishers.

The use of the proper type of extinguisher for each class of fire will give the best control of the situation and avoid compounding the problem. The class of fires given here is based on the type of material being consumed.

Class A Fires: (For wood, paper, textiles, and similar materials.) Use foam, water, carbon dioxide gas or almost any kind of extinguisher.

CHOOSE AN EXTINGUISHER BY CLASS OF FIRE---DON'T GUESS.

Class B Fires: (For grease, oil, paint, and related materials.) Use foam, dry chemical or vaporizing liquid extinguishers.

Class C Fires: (All fires in electrical equipment and in areas where live electricity is present.) Use carbon dioxide, dry chemical, or vaporizing liquid extinguishers only.

Class D Fires: (Fires involving sodium, zinc, magnesium, and other elements). These fires should be smothered with fine dry soda ash, sand, or graphite.

7.163 Acknowledgments

Portions of this section were taken from material written by A.E. Greenberg, "Safety and Hygiene," which appeared in the California Water Pollution Control Association's *OPERATORS' LABORATORY MANUAL*. Some of the ideas and material also came from the *FISHER SAFETY MANUAL*.

7.164 Additional Reading

1. *FISHER SAFETY MANUAL*. Available from Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, PA 15210. Price $6.00.
2. *SAFETY IN THE CHEMICAL LABORATORY*. Edited by Norman V. Steere. 3 Volumes. Price $21.90. Order from Journal of Chemical Education, Office of Publications Coordinator, 238 Kent Road, Springfield, PA 19064.
3. *GENERAL INDUSTRY, OSHA, SAFETY AND HEALTH STANDARDS* (29 CFR 1910), OSHA 2206, revised January 1976. Obtain from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Stock Number 029-015-00054-6. Price $6.50.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 402.

7.1G List five laboratory hazards.

7.1H Why should you not work all alone in a laboratory?

7.1I How would you dispose of a corrosive acid?

7.1J True or False? You may *ADD ACID* to water, but never water to acid.

End of Lesson 1 of 5 Lessons on LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. LABORATORY PROCEDURES

(Lesson 1 of 5 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook.

1. How do the operators of water treatment plants use the results from laboratory tests?
2. Why must chemicals be properly labeled?
3. How are pipets emptied or drained? Why is this procedure important?
4. How would you titrate a test solution?
5. Why should work with certain chemicals be conducted under a ventilated laboratory hood?
6. Why should water not be poured on certain types of fires?
7. List as many of the seven basic rules for working in a laboratory as you can remember.

CHAPTER 7. LABORATORY PROCEDURES

(Lesson 2 of 5 Lessons)

7.2 SAMPLING

7.20 Importance of Sampling

Sampling is a vital part of studying the quality of water in a water treatment process, distribution system, or source of water supply. The major source of error in the whole process of obtaining water quality information often occurs during sampling. This fact is not well enough recognized and cannot be over emphasized.

In any type of testing program where only small samples (a liter or two) are withdrawn from perhaps millions of gallons of water under examination, there is potential uncertainty because of possible sampling errors. Water treatment decisions based upon incorrect data may be made if sampling is performed in a careless and thoughtless manner. Obtaining good results will depend to a great extent upon the following factors:

1. Insuring that the sample taken is truly representative of the water under consideration,
2. Using proper sample techniques, and
3. Protecting and preserving the samples until they are analyzed.

The greatest errors in laboratory tests are usually caused by improper sampling, poor preservation, or lack of enough mixing during testing. The accuracy of your analysis is only as good as the care that was taken in obtaining a representative sample.[4]

7.21 Representative Sampling

7.210 Importance of Representative Sampling

The sampling of a tank or a lake that is completely mixed is a simple matter. Unfortunately, most bodies of water are not well mixed and obtaining samples that are truly representative of the whole body depends to a great degree upon sampling technique. A sample that is properly mixed (integrated) by taking small portions of the water at points distributed over the whole body represents the material better than a sample collected from a single point. The more portions taken, the more nearly the sample represents the original. The sample error would reach zero when the size of the sample became equal to the original volume of material being sampled, but for obvious reasons this method of decreasing sample error is not practical. The size of sample depends on which water quality indicators are being tested and how many. Every precaution must be taken to insure that the sample collected is as representative of the water source or process being examined as is feasible.

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[4] *Representative Sample. A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.*

7.211 Source Water Sampling

RIVERS. To adequately determine the composition of a flowing stream, each sample (or set of samples taken at the same time) must be representative of the entire flow at the sampling point at that instant. Furthermore, the sampling process must be repeated frequently enough to show significant changes of water quality that may occur over time in the water passing the sampling point.

On small or medium-sized streams, it is usually possible to find a sampling point at which the composition of the water is presumably uniform at all depths and across the stream. Obtaining representative samples in these streams is relatively simple. For larger streams, more than one sample may be required. A portable conductivity meter is very useful in selecting good sample sites.

RESERVOIRS AND LAKES. Water stored in reservoirs and lakes is usually poorly mixed. Thermal stratification and associated depth changes in water composition (such as dissolved oxygen) are among the most frequently observed effects. Single samples can therefore be assumed to represent only the spot of water from which the sample came. Therefore, a number of samples must be collected at different depths and from different areas of the impoundment to accurately sample reservoirs and lakes.

GROUNDWATER. Most of the physical factors which promote mixing in surface waters are absent or much less effective in groundwater systems. Wells usually draw water from a considerable thickness of saturated rock and often from several different strata. These water components are mixed by the turbulent flow of water in the well before they reach the surface and become available for sampling. Most techniques for well sampling and exploration are usable only in unfinished or non-operating wells. Usually the only means of sampling the water tapped by a well is the collection of a pumped sample. The operator is cautioned to remember that well pumps and casings can contribute to sample contamination. If a pump has not run for an extended period of time prior to sampling, the water collected may not be representative of the normal water quality.

7.212 In-Plant Sampling

Collection of representative samples within the water treatment plants is really no different from sample collection in a stream or river. The operator simply wants to be sure the water sampled is representative of the water passing that sample point. In many water plants, money is spent to purchase sample pumps and piping only to sample from a point that is not representative of the passing water. A sample tap in a dead area of a reservoir or on the floor of a process basin serves no purpose in helping the plant operator with control of water quality. The operator is urged to find each and every sample point and insure it is located to provide a useful and representative sample. If the sampling point is not properly located, plan to move the piping to a better location.

7.213 Distribution System Sampling

Representative sampling in the distribution system is a true indication of system water quality. Results of sampling should show if there are quality changes in the entire, or parts of, the system and may point to the source of a problem (such as tastes and/or odors). Sampling points should be selected, in part, to trace the course from finished water source (at the well or plant) through the transmission mains, and then through the major and minor arteries of the system. A sampling point on a major artery, or on an active main directly connected to it, would be representative of the water quality being furnished to a subdivision of this network. Generally, these primary points are used as "official" sample points in evaluating prevailing water quality.

Obtaining a representative sample from the distribution system is not as easy as it might seem. One would think almost any faucet would do, but experience has shown otherwise. Local conditions at the tap and in its connection to the main can easily make the point unrepresentative of water being furnished to your consumers.

The truest evaluation of a water sample can be obtained from samples drawn directly from the main. You might think that samples taken from a fire hydrant would prove satisfactory, but this is usually not the case. The problem with fire hydrants as sampling points is that they give erratic (uneven) results due to the way they are constructed and their lack of use. In general, an ideal sample station is one that has a short, direct connection with the main and is made of corrosion-resistant material.

FREE
SAMPLES
TAKE ONE

In most smaller water systems, special sample taps are not available. Therefore, customer's faucets must be used to collect samples. The best sample points are front yard faucets on homes supplied by short service lines (homes with short service lines are located on the same side of the street as the water main).

If the customer is home, you should contact the person in the home and obtain permission to collect the sample. Disconnect the hose from the faucet if one is attached and don't forget to reconnect the hose when finished collecting the sample. Open the faucet to a convenient flow for sampling (usually about half a gallon per minute). Allow the water to flow until the water in the service line has been replaced twice. Since 50 feet (15 m) of three-quarter inch (18 mm) pipe contains over one gallon (3.8 liters), four or five minutes will be required to replace the water in the line twice. Collect the sample. Be sure the sample container does not touch the faucet.

Do not try to save time by turning the faucet handle to wide open to flush the service line. This will disturb sediment and incrustations in the line which must be flushed out before the sample can be collected.

FORMULAS

To estimate the flow from a faucet, use a gallon jug and a watch. If you want a flow of half a gallon per minute, then the jug should be half full in one minute or completely full in two minutes.

$$\text{Flow, GPM} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

To calculate the volume of a service line, multiply the area of the pipe in square feet times the length of the pipe in feet to obtain cubic feet. The diameter of a pipe is given in inches, so this value must be divided by 12 inches per foot to obtain a volume in cubic feet. Multiply cubic feet by 7.48 gallons per cubic foot to obtain the volume in gallons.

$$\text{Pipe Volume, cu ft} = \frac{\text{(Pipe Area, sq in)(Pipe Length, ft)}}{\text{144 sq in/sq ft}}$$

$$\text{Pipe Volume, gal} = \text{(Pipe Volume, cu ft)(7.48 gal/cu ft)}$$

To determine the time to allow water to flow from a faucet to flush a service line twice, divide the pipe volume in gallons by the flow in gallons per minute. Then multiply the result by two so the line will be flushed twice.

$$\text{Flushing Time, min} = \frac{\text{(Pipe Volume, gal)(2)}}{\text{Flow, gal/min}}$$

EXAMPLE 2

How long should a three-quarter inch service line 80 feet long be flushed if the flow is 0.5 GPM?

KNOWN	**UNKNOWN**
Diameter, in = ¾ in = 0.75 in	Flushing Time, min
Length, ft = 80 ft	
Flow, GPM = 0.5 GPM	

Calculate the pipe volume in cubic feet and then in gallons.

$$\begin{aligned}\text{Pipe Volume, cu ft} &= \frac{\text{(Pipe Area, sq in)(Pipe Length, ft)}}{\text{144 sq in/sq ft}}\\ &= \frac{(0.785)(0.75\text{ in})^2(80\text{ ft})}{\text{144 sq in/sq ft}}\\ &= 0.245\text{ cu ft}\end{aligned}$$

$$\begin{aligned}\text{Pipe Volume, gal} &= \text{(Pipe Volume, cu ft)(7.48 gal/cu ft)}\\ &= (0.245\text{ cu ft})(7.48\text{ gal/cu ft})\\ &= 1.833\text{ gal}\end{aligned}$$

Calculate the flushing time for the service line in minutes.

$$\begin{aligned}\text{Flushing Time, min} &= \frac{\text{(Pipe Volume, gal)(2)}}{\text{Flow, gal/min}}\\ &= \frac{(1.833\text{ gal})(2)}{0.5\text{ GPM}}\\ &= 7.3\text{ min}\\ \text{or} &= 7\text{ min} + (0.3\text{ min})(60\text{ sec/min})\\ &= 7\text{ min and 18 sec}\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 402.

7.2A What are frequently the greatest causes of errors in laboratory tests?

7.2B Why must a representative sample be collected?

7.2C How are sampling points selected in a distribution system?

7.22 Types of Samples

There are generally two types of samples collected by waterworks operators, and either type may be obtained manually or automatically. The two types are grab samples and composite samples.

7.220 Grab Samples

A grab sample is a single water sample collected at no specific time. Grab samples will show the water characteristics at the time the sample was taken. A grab sample may be preferred over a composite sample when:

1. The water to be sampled does not flow on a continuous basis,
2. The water's characteristics are relatively constant, and
3. The water is to be analyzed for water quality indicators that may change with time, such as dissolved gases, coliform bacteria, residual chlorine, temperature, and pH.

7.221 Composite Samples

In many processes, the water quality is changing from moment to moment or hour to hour. A continuous sampler-analyzer would give the most accurate results in these cases. However, since operators themselves are often the sampler-analyzer, continuous analysis would leave little time for anything but sampling and testing. Except for tests which cannot wait due to rapid physical, chemical, or biological changes of the sample (such as tests for dissolved oxygen, pH, and temperature) a fair compromise may be reached by taking samples throughout the day at hourly or two-hour intervals. Each sample should be refrigerated immediately after it is collected. At the end of 24 hours, a portion of each sample is mixed with the other samples. The size of the portion is in direct proportion to the flow when the sample was collected and the total size of sample needed for testing. For example, if hourly samples were collected, when the flow was 1.2 MGD, use a 12 *mL* portion sample and when the flow was 1.5 MGD, use a 15 *mL* portion of the sample. The resulting mixture of portions of samples is called a *COMPOSITE SAMPLE*. In no case, however, should a composite sample be collected for bacteriological examination.

When the samples are taken, they can either be set aside to be combined later or combined as they are collected. In both cases, they should be stored at a temperature of 4°C until they are analyzed.

7.23 Sampling Devices

Automatic sampling devices are wonderful time-savers but are expensive. As with anything automatic, problems do arise and the operator should be on the look out for potential difficulties.

Manual sampling equipment includes dippers, weighted bottles, hand-operated pumps, and cross-section samplers. Dippers consist of wide-mouth corrosion-resistant containers (such as cans or jars) on long handles that collect a sample for testing. A weighted bottle is a collection container which is lowered to a desired depth. At this depth a cord or wire removes the bottle stopper so the bottle can be filled (see Figure 7.5).

Some water treatment facilities use sample pumps to collect the sample and transport it to a central location. The pump and its associated piping should be corrosion-resistant and sized to deliver the sample at a high enough velocity to prevent sedimentation in the sample line.

Many water agencies have designed and installed special sampling stations throughout their distribution systems (see Figure 7.6). These stations provide an excellent location to sample the actual quality of water in your distribution system.

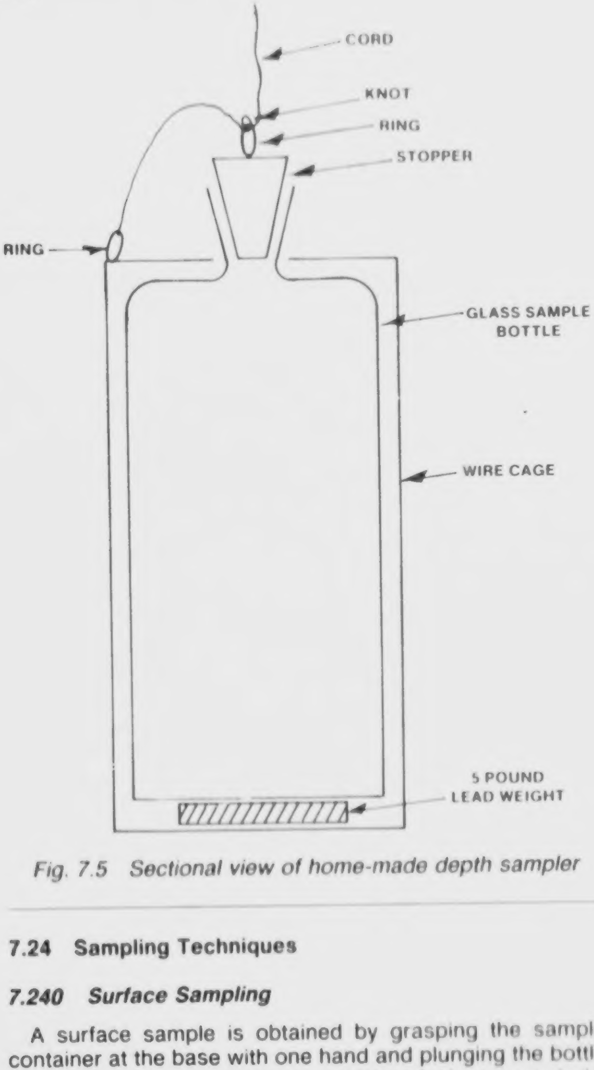

Fig. 7.5 Sectional view of home-made depth sampler

7.24 Sampling Techniques

7.240 Surface Sampling

A surface sample is obtained by grasping the sample container at the base with one hand and plunging the bottle mouth-down into the water to avoid introducing any material floating on the surface. Position the mouth of the bottle into the current and away from the hand of the collector (see Figure 7.7). If the water is not flowing, then an artifical current can be created by moving the bottle horizontally in the direction it is pointed and away from the sampler. Tip the bottle slightly upwards to allow air to exit so the bottle can fill. Tightly stopper and label the bottle.

Place the bottle in a weighted frame that holds the bottle securely when sampling from a walkway or other structure above a body of water. Remove the stopper or lid and lower the device to the water surface. A nylon rope which does not absorb water and will not rot is recommended. Face the bottle mouth upstream by swinging the sampling device downstream and then allow it to drop into the water, without slack in the rope. Pull the sample device rapidly upstream and out of the water simulating (imitating) the scooping motion of the hand-sampling described previously. Take care not to dislodge dirt or other debris that might fall into the open sample container from above. Be sure to label the container when sampling is completed.

7.241 Depth Sampling

Several additional pieces of equipment are needed for collection of depth samples from basins, tanks, lakes, and reservoirs. These depth samplers require lowering the sample device and container to the desired water depth, then operating, filling, and closing the container and returning the device to the surface. Although depth measurements are best made with a pre-marked steel cable, the sample depths can be determined by pre-measuring and marking a nylon rope at intervals with a non-smearing ink, paint, or finger-nail

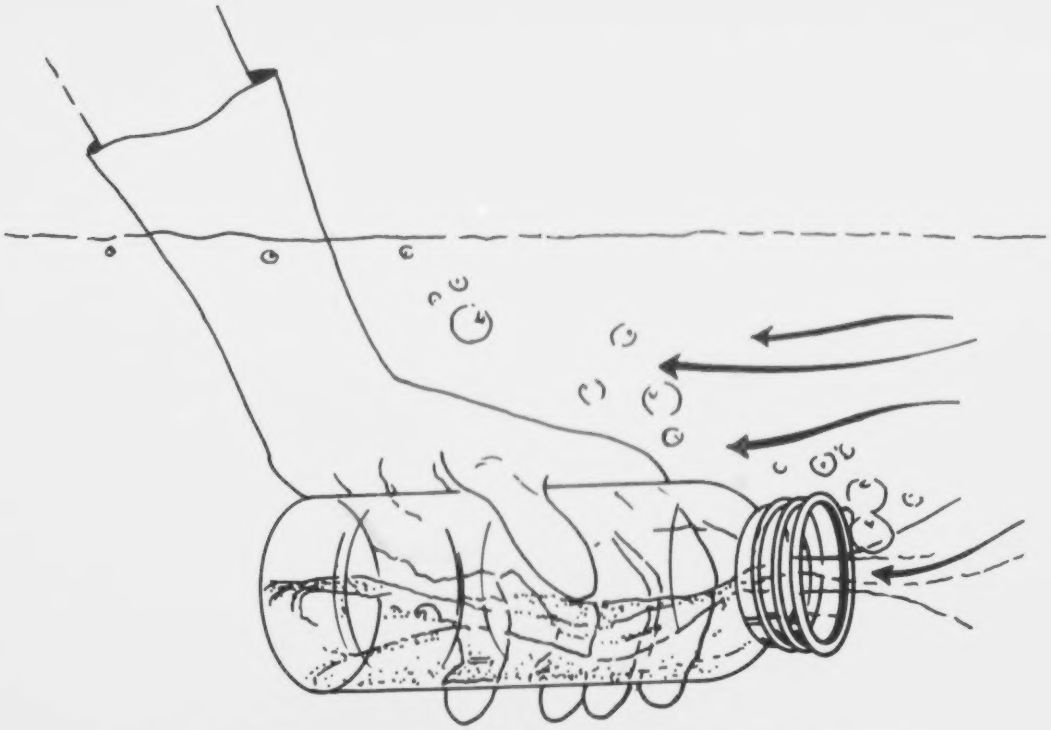

Fig. 7.7 Demonstration of technique used in grab sampling of surface waters

(Source: U.S. EPA, "Microbiological Methods for Monitoring the Environment," Dec. 1978.)

polish. One of the most common commercial devices is called a Kemmerer Sampler (see Figure 7.8). This type of depth sampler consists of a cylindrical tube that contains a rubber stopper or valve at each end. The device is lowered into the water in the open position and the water sample is trapped in the cylinder when the valces are closed by the dropped messenger.

Figures 7.5 and 7.9 show typical depth samplers. These samplers are lowered to the desired depth. A jerk on the cord will remove the stopper and allow the bottle in the depth sampler to fill. Good samples can be collected in depths of water up to 40 feet (12 m).

7.242 Water Tap Sampling

To collect samples from water main connections, first flush the service line for a brief period of time. Samples should not be taken from drinking fountains, restrooms, or taps that have aerators. Aerators can change water quality indicators such as pH and dissolved oxygen, and can harbor bacteria under some conditions. Do not sample from taps surrounded by excessive foliage (leaves, flowers) or taps that are dirty, corroded, or are leaking. Never collect a sample from a hose or any other attachment fastened to a faucet. Care must be taken to be sure that the sample collector does not come in contact with the faucet.

7.25 Sampling Containers and Preservation of Samples

The shorter the time that elapses between the actual collection of the sample and the analysis, the more reliable your results will be. Some tests, such as residual chlorine and temperature, require immediate analysis, while others can be transported to the laboratory. A summary of acceptable smple containers, preservative, and maximum time between sampling and analysis is shown on Table 7.2.

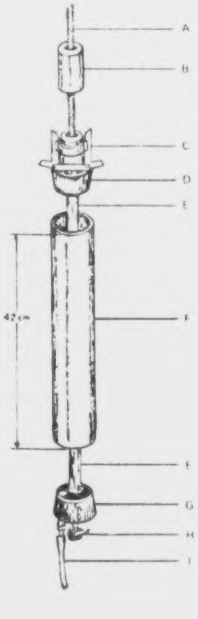

Fig. 7.8 Kemmerer Depth Sampler. (A) nylon line, (B) messenger, (C) catch set so that the sampler is open, (D) top rubber valve, (E) connecting rod between the valves, (F) tube body, (G) bottom rubber valve, (H) knot at the bottom of the suspension line and (I) rubber tubing attached to the spring-loaded check valve.

Source: U.S. EPA "Microbiological Methods for Monitoring the Environment," December 1978.

TABLE 7.2 RECOMMENDATION FOR SAMPLING AND PRESERVATION OF SAMPLES ACCORDING TO MEASUREMENT[a]

Measurement	Vol. Req. (mL)	Container[b]	Preservative	Maximum Holding Time[c]
PHYSICAL PROPERTIES				
Color	50	P,G	Cool, 4°C	48 hours
Conductance	100	P,G	Cool, 4°C	28 days
Hardness[d]	100	P,G	HNO_3 to $pH < 2$ H_2SO_4 to $pH < 2$	6 months
Odor	200	G only	Cool, 4°C	24 hours
pH[d]	25	P,G	Det. on site	Immediately
Residue, Filterable	100	P,G	Cool, 4°C	48 hours
Temperature	1000	P,G	Det. on site	Immediately
Turbidity	100	P,G	Cool, 4°C	48 hours
METALS (Fe, Mn)				
Dissolved	200	P,G	Filter on site HNO_3 to $pH < 2$	6 months
Suspended	200		Filter on site	6 months
Total	100	P,G	HNO_3 to $pH < 2$	6 months
INORGANICS, NON-METALLICS				
Acidity	100	P,G	Cool, 4°C	14 days
Alkalinity	100	P,G	Cool, 4°C	14 days
Bromide	100	P,G	None Req.	28 days
Chloride	50	P,G	None Req.	28 days
Chlorine	200	P,G	Det. on site	Immediately
Cyanide	500	P,G	Cool, 4°C NaOH to $pH > 12$	14 days
Fluoride	300	P,G	None Req.	28 days
Iodide	100	P,G	Cool, 4°C	24 hours
Nitrogen				
Ammonia	400	P,G	Cool, 4°C H_2SO_4 to $pH < 2$	28 days
Kjeldahl, Total	500	P,G	Cool, 4°C H_2SO_4 to $pH < 2$	28 days
Nitrate plus Nitrite	100	P,G	Cool, 4°C H_2SO_4 to $pH < 2$	28 days
Nitrate	100	P,G	Cool, 4°C	48 hours
Nitrite	50	P,G	Cool, 4°C	48 hours
Dissolved Oxygen				
Probe	300	G only	Det. on site	Immediately
Winkler	300	G only	Fix on site	8 hours
Phosphorus				
Ortho-phosphate, Dissolved	50	P,G	Filter on site Cool, 4°C	24 hours
Hydrolyzable	50	P,G	Cool, 4°C H_2SO_4 to $pH < 2$	24 hours
Total	50	P,G	Cool, 4°C H_2SO_4 to $pH < 2$	28 days
Total, Dissolved	50	P,G	Filter on site Cool, 4°C H_2SO_4 to $pH < 2$	24 hours
Silica	50	P only	Cool, 4°C	28 days
Sulfate	50	P,G	Cool, 4°C	28 days
Sulfide	500	P,G	Cool, 4°C 2 mL zinc acetate	7 days
Sulfite	50	P,G	Det. on site	Immediately

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[a] "Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act;" by U. S. Environmental Protection Agency. Federal Register, Part VIII, Vol. 49, NO. 209, Friday, October 26, 1984, 40 CFR Part 136.

[b] Polyethylene (P) or Glass (G). For metals, polyethylene with a polypropylene cap (no liner) is preferred.

[c] Holding times listed above are recommended for properly preserved samples based on currently available data. It is recognized that for some sample types, extension of these times may be possible while for other types, these times may be too long. Where shipping regulations prevent the use of the proper preservation technique or the holding time is exceeded, such as the case of a 24-hour composite, the final reported data for these samples should indicate the specific variance.

[d] Hardness and pH are usually considered chemical properties of water rather than physical properties.

SPECIAL NOTE

Whenever you collect a sample for a bacteriological test (coliforms), be sure to use a sterile plastic or glass bottle. If the sample contains any chlorine residual, sufficient sodium thiosulfate should be added to neutralize all of the chlorine residual. Usually two drops (0.1 mL) of ten percent sodium thiosulfate for every 100 mL of sample is sufficient, unless you are disinfecting mains or storage tanks.

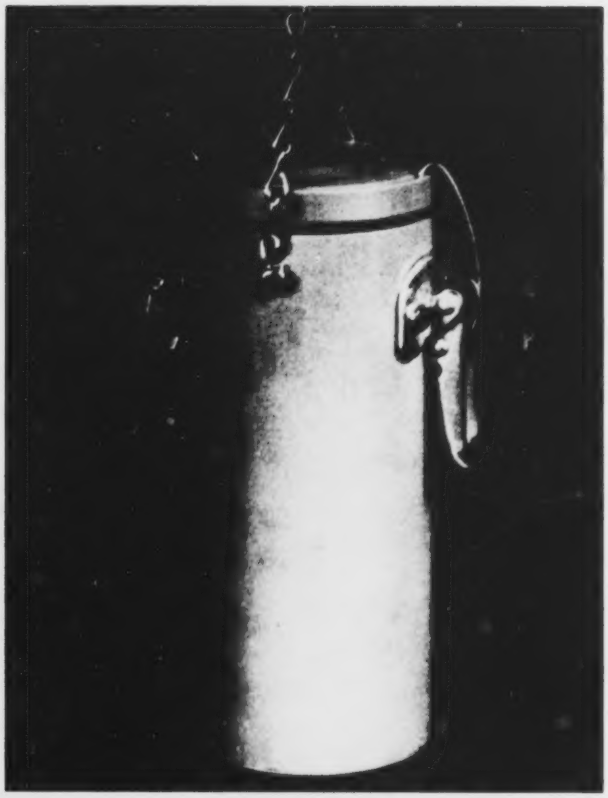


Fig 7.9 Depth sampler
(Permission of HACH Company)

Whatever types of container you use, clearly identify the sample location, date and time of collection, name of collector, and any other pertinent information.

7.26 Additional Reading

1. See page 37, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 402.

7.2D What are the two general types of samples collected by water treatment personnel?

7.2E List three water quality indicators that are usually measured with a grab sample.

7.2F How would you collect a depth sample from a lake?

7.2G Samples should not be collected from water taps under what conditions?

7.2H What information should be recorded when a sample is collected?

End of Lesson 2 of 5 Lessons
on
LABORATORY
PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. LABORATORY PROCEDURES

(Lesson 2 of 5 Lessons)

Write the answers to these questions in your notebook. The question numbering continues from Lesson 1.

8. Why are proper sampling procedures important?
9. What is meant by a representative sample?
10. How would you obtain a representative sample?
11. Under what conditions and why would you preserve a sample?

CHAPTER 7. LABORATORY PROCEDURES

(Lesson 3 of 5 Lessons)

7.3 WATER LABORATORY TESTS

1. Alkalinity

A. Discussion

The alkalinity of a water sample is a measure of the water's capacity to neutralize acids. In natural and treated waters, alkalinity is the result of bicarbonates, carbonates, and hydroxides of the metals of calcium, magnesium, and sodium.

Many of the chemicals used in water treatment, such as alum, chlorine, or lime, cause changes in alkalinity. The alkalinity determination is a useful tool in calculating chemical dosages needed in coagulation and water softening. Alkalinity must also be known to calculate corrosivity and to estimate the carbonate hardness of water. Alkalinity is usually expressed in terms of *CALCIUM CARBONATE* ($CaCO_3$).[5]

There are five alkalinity conditions possible in a water sample: (1) bicarbonate alone, (2) bicarbonate and carbonate, (3) carbonate alone, (4) carbonate and hydroxide, and (5) hydroxide alone. These five conditions may be distinguished and quantities determined from the results of acid titrations by the method given below.

B. What is Tested

Sample	Common Range, mg/*L*
Raw and Treated Surface Water	20 - 300
Well Water	80 - 500

C. Apparatus Required

pH meter
reference electrode
glass electrode
magnetic stirrer
magnetic stir-bar
analytical balance
graduated cylinder (100 m*L*)
buret (25 m*L*)
buret support
beaker (250 m*L*)
wash bottle
desiccator

D. Reagents

(*NOTE:* Standardized solutions are commercially available for most reagents. Refer to *STANDARD METHODS* if you wish to prepare your own reagents.)

1. Sodium carbonate (Na_2CO_3) solution, approximately 0.05 *N*.
2. Sulfuric acid (H_2SO_4), 0.1 *N*.
3. Standard sulfuric acid, 0.02 *N*: Dilute 200 m*L* 0.10 *N* standard acid to 1 liter using a volumetric flask. To determine the volume to be diluted, use the following formula:

$$\text{Volume diluted, m}L = \frac{(\text{Standard, } 0.02\ N) \times (1000\ \text{m}L)}{(\text{Calculated Normality, } 0.10\ N)}$$

$$= \frac{(0.02\ N) \times (1000\ \text{m}L)}{(0.10\ N)}$$

$$= 200\ \text{m}L$$

E. Procedure

Total and Phenolphthalein Alkalinity

1. Take a clean beaker and add 100 m*L* of sample (or other sample volume that will give a titration volume of less than 50 m*L* of acid titrant).
2. Place electrodes of pH meter into beaker containing sample.
3. Stir sample slowly (with a magnetic stirrer if possible).
4. Check pH of sample. If pH is 8.3 or below, then there is no phenolphthalein alkalinity present and you can go to step 6.
5. If the pH is greater than 8.3, titrate very carefully to a pH of 8.3 with 0.02 *N* H_2SO_4. Record the amount of acid used to this point.
6. **Continue to titrate to pH 4.5 with 0.02 *N* H_2SO_4.[6] Record the total amount of acid used from starting point to finish.**
7. Calculate Total and Phenolphthalein (if present) Alkalinities.

F. Example

Results from alkalinity titrations on a finished water sample were as follows:

Sample size = 100 m*L*
m*L* titrant used to pH 8.3, A = 0.5 m*L*
total m*L* of titrant used, B = 6.8 m*L*
Acid Normality, N = 0.02 *N* H_2SO_4

G. Calculations

Phenolphthalein Alkalinity, and mg/*L* as $CaCO_3$

$$= \frac{A \times N \times 50{,}000}{\text{m}L \text{ of sample}}$$

$$= \frac{(0.5\ \text{m}L) \times (0.02\ N) \times 50{,}000}{100\ \text{m}L}$$

$$= 5\ \text{mg}/L$$

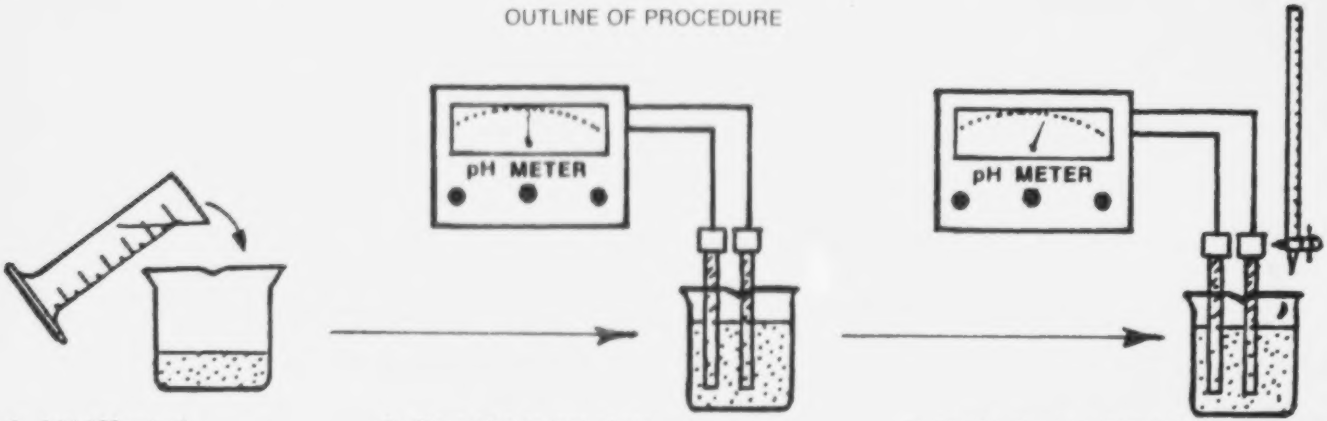
---

[5] *Calcium Carbonate ($CaCO_3$) Equivalent. An expression of the concentration of specific constituents in water in terms of their equivalence to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.*

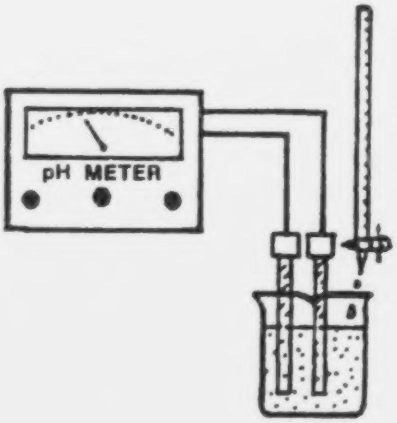
[6] ***STANDARD METHODS, 16th Edition, page 270, recommends training to a pH of 4.5 for routine or automated analyses. However, other pH levels are suggested for various levels of alkalinity.***

(Alkalinity)

OUTLINE OF PROCEDURE



1. Add 100 m*L* of sample.
2. Place electrodes* of pH meter in beaker.
3. Titrate down to pH 8.3 (if necessary), with 0.02 *N* H_2SO_4.



4. Continued to titrate to pH 4.5.

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* Some pH meters have a single "combination" electrode.

Total Alkalinity, mg/*L* as $CaCO_3$

$$= \frac{B \times N \times 50{,}000}{mL\ of\ sample}$$

$$= \frac{(6.8\ mL) \times (0.02\ N) \times 50{,}000}{100\ mL}$$

$$= 68\ mg/L$$

H. Interpretation of Results

From the test results and the information given below, the different types of alkalinity contained in a water sample can be determined.

Titration Result	Alkalinity, mg/*L* as $CaCO_3$		
	Bicarbonate	Carbonate	Hydroxide
P = 0	T	0	0
P is less than ½ T	T - 2P	2P	0
P = ½ T	0	2P	0
P is greater than ½ T	0	2T - 2P	2P - T
P = T	0	0	T

where P = phenolphthalein alkalinity
T = total alkalinity

Example: The example in "F" above gave the following results:

phenolphthalein alkalinity = 5 mg/*L*
total alkalinity = 68 mg/*L*

Since the phenolphthalein alkalinity (5 mg/*L*) is less than one half of the total alkalinity (68 mg/*L*) from the table, then there is bicarbonate and carbonate alkalinity in the water.

The bicarbonate alkalinity in this case is equal to T − 2P or 68 mg/*L* − (2 × 5 mg/*L*) = 58 mg/*L* as $CaCO_3$.

The carbonate alkalinity is equal to 2P or 2 × 5 mg/*L* = 10 mg/*L* as $CaCO_3$.

I. Precautions

1. The sample should be analyzed as soon as possible, at least within a few hours after collection.
2. The sample should not be agitated, warmed, filtered, diluted, concentrated, or altered in any way.

J. Reference

1. See page 269, *STANDARD METHODS*, 16th Edition.
2. See page 310-1-1 *METHODS FOR CHEMICAL ANALYSIS OF WATER AND WASTES*, March 1979.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 402.

7.3A What chemicals used in water treatment will cause changes in alkalinity?

7.3B Why is it important to know the alkalinity of a water sample?

2. Chlorine Residual

A. Discussion

Chlorine is not only an excellent disinfectant but also serves to react with iron, manganese, protein substances, sulfide, and many taste- and odor-producing compounds to help improve the quality of treated water. In addition, chlorine helps to control microorganisms that might interfere with coagulation and flocculation, keeps filter media free of slime growths, and helps bleach out undesirable color.

There are two general types of residual chlorine produced in chlorinated water. They are (1) free residual chlorine and (2) combined residual chlorine. Free residual chlorine refers to chlorine (Cl_2), hypochlorus acid (HOCl), and the hypochlorite ion (OCl^-). Combined residual chlorine generally refers to the chlorine-ammonia compounds of monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3 or nitrogen trichloride). Both types of residuals act as disinfectants, but differ in their capacity to produce a germ-free water supply during the same contact time.

In addition to all the positive aspects of chlorination, there may be some adverse effects. Potentially carcinogenic chlororganic compounds such as chloroform and other THMs may be formed during the chlorination process. To minimize any adverse effects, the operator should be familiar with the concentrations of free and combined residual chlorine produced in a water supply following chlorination. Both residuals are extremely important in producing a potable water that is not only safe to drink but is also free of objectionable tastes and odors.

B. What is Tested

Source	Common Range Residual Chlorine, mg/*L* Free	Common Range Residual Chlorine, mg/*L* Total
Chlorinated Raw Surface Water (Pre-Chlorination)	0.3 to 3	0.5 to 5
Chlorinated Finished Surface Water (Post-Chlorination)	0.2 to 1	0.3 to 1.5
Well Water	0.2 to 1	0.2 to 1

C. Methods

There are seven methods listed for measuring residual chlorine in the 16th Edition of *STANDARD METHODS*. Selection of the most practical and appropriate procedure in any particular instance generally depends upon the characteristics of the water being examined. The *AMPEROMETRIC*[7] titration method is a standard of comparison for determining free or combined chlorine residual. This method is relatively free of interferences but does require greater operator skill to obtain good results. In addition, the titration instrument is expensive.

The DPD[8] methods are simpler to perform than amperometric titration but are subject to interferences due to manganese. Field comparator kits are available from several suppliers such as Hellige, Wallace & Tiernan, and Hach.

D. Apparatus Required

1. Amperometric Titration Method

   See page 303, *STANDARD METHODS*, 16th Edition and amperometric titrator's instruction manual.

2. DPD Colorimetric Method (Field Comparator Kit)

   Field Comparator
   Sample cells

3. DPD Titrimetric Method[9]

   Graduated cylinder (100 m*L*)
   Pipets (1 and 10 m*L*)
   Flask, Erlenmeyer (250 m*L*)
   Buret (10 m*L*)
   Magnetic Stirrer
   Magnetic stir-bar
   Balance, analytical

---

[7] *Amperometric (am-PURR-o-MET-rick). A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is a means of measuring concentrations of certain substances in water.*

[8] *DPD. A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with standards. DPD stands for N, N-diethyl-p-phenylene-diamine.*

[9] *Some regulatory agencies require the use of the DPD Titrimetric Method if chlorine residual testing is used in place of some of the coliform tests.*

(Chlorine Residual)

E. Reagents

(*NOTE*: Prepared reagents may be purchased from laboratory chemical supply houses.)

Amperometric Titration Method

1. Standard phenylarsine oxide (PAO) solution, 0.00564 *N*
   CAUTION: Toxic — avoid ingestion.
2. Acetate buffer solution, pH 4.
3. Phosphate buffer solution, pH 7.
4. Potassium iodide solution.

   Store in brown glass-stoppered bottle, preferably in the refrigerator. Discard when solution becomes yellow.

DPD Colorimetric Method (Field Comparator Kit)

Use reagents supplied by kit manufacturer.

DPD Titrimetric Method

1. 1 + 3 H_2SO_4. *CAREFULLY* add 10 m*L* concentrated sulfuric acid to 30 m*L* distilled water. Cool.
2. Phosphate Buffer Solution.
3. DPD Indicator Solution.
4. Standard Ferrous Ammonium Sulfate (FAS) Titrant, 0.00282 *N*.
5. Potassium iodide, KI, crystals.

F. Procedure

Amperometric Titration Method

Follow manufacturer's instructions.

DPD Colorimetric Method (Field Comparator Kit)

To measure chlorine residuals you should follow the directions provided by the manufacturer of the equipment or instrument you are using.

If you are disinfecting clear wells, distribution reservoirs or mains and very high chlorine residuals must be measured, a drop-dilution technique can be used to estimate the chlorine residual. The procedure is as follows:

1. Add 10 m*L* of distilled water and one powder pillow of DPD reagent (or 0.5 m*L* of DPD solution) to the sample tube of the test kit.
2. Add a sample of the water being tested on a drop-by-drop basis to the sample tube until a color is produced.
3. Record the number of drops added to the sample tube. Assume one drop equals 0.05 m*L*.
4. Determine the chlorine residual in the sample as a result of the color produced and record the residual in milligrams per liter.

EXAMPLE 3

The recorded chlorine residual is 0.3 mg/*L*. Two drops of sample produced a chlorine residual of 0.3 mg/*L* in 10 m*L* of distilled water. Assume 0.05 m*L* per drop.

Known		**Unknown**
Chlorine Residual, mg/*L*	= 0.3 mg/*L*	Actual Chlorine Residual, mg/*L*
Sample Volume, drops	= 2 drops	
Distilled Water, m*L*	= 10 m*L*	

Calculate the actual residual in milligrams per liter.

$$\text{Actual Chlorine Residual, mg}/L = \frac{(\text{Chlorine Residual, mg}/L)(\text{Distilled Water, m}L)}{(\text{Sample Volume, drops})(0.05\text{ m}L/\text{drop})}$$

$$= \frac{(0.3\text{ mg}/L)(10\text{ m}L)}{(2\text{ drops})(0.05\text{ m}L/\text{drop})}$$

$$= 30\text{ mg}/L$$

DPD Titrimetric Method

FOR FREE RESIDUAL CHLORINE

1. Place 5 m*L* each of buffer reagent and DPD indicator in a 250 m*L* flask and mix.
2. Add 100 m*L* of sample and mix.
3. Titrate rapidly with standard FAS titrant until red color is discharged (disappears).
4. Record amount of FAS used (Reading A). If combined residual chlorine fractions are desired, continue to next step.

FOR COMBINED RESIDUAL CHLORINE

Monochloramine

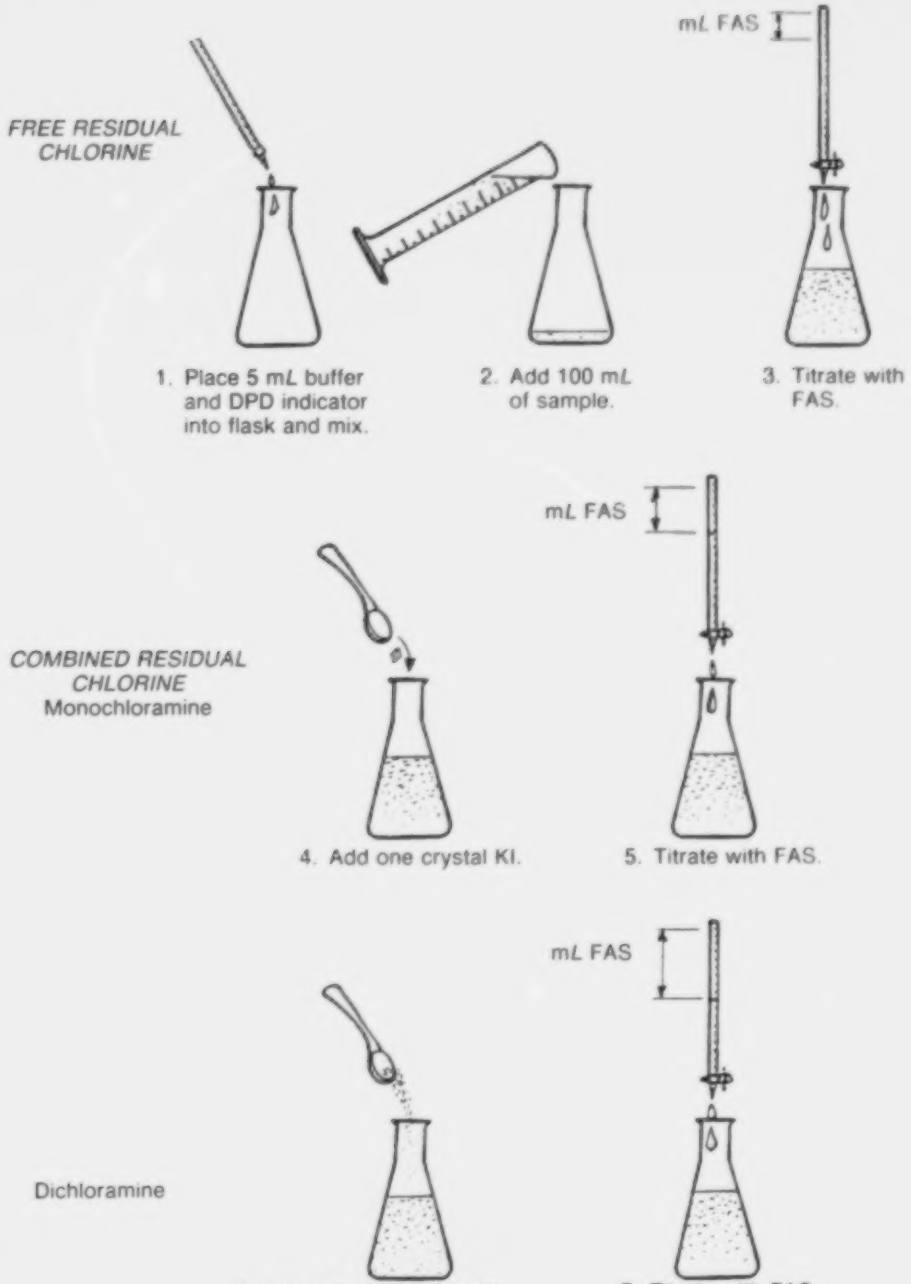
5. Add one very small crystal of KI and mix. If monochloramine is present, the red color will re-appear.
6. Continue titrating carefully until red color again disappears.
7. Record reading of FAS in the buret used to this point (this includes amount used above). This is Reading B.

Dichloramine

8. Add several crystals KI (about 1 g) and mix until dissolved.
9. Let stand 2 minutes.
10. Continue amount of FAS used to this point. This includes amounts used in two previous titrations for free and monochloramine. This is reading C.

NOTE: Manufacturers of laboratory equipment are continually developing faster and more accurate ways to measure chlorine residual. If you have new equipment, follow the manufacturer's procedures.

OUTLINE OF PROCEDURE


FREE RESIDUAL CHLORINE
mL FAS
COMBINED RESIDUAL CHLORINE
Monochloramine
mL FAS
Dichloramine
mL FAS

1. Place 5 mL buffer and DPD indicator into flask and mix.
2. Add 100 mL of sample.
3. Titrate with FAS.
4. Add one crystal KI.
5. Titrate with FAS.
6. Add several crystals KI.
7. Titrate with FAS.

(Chlorine Demand)

G. Precautions

1. For accurate results, careful pH control is essential.

   The pH of the sample, buffer, and DPD indicator together should be between 6.2 and 6.5.

2. If the sample contains oxidized manganese, an inhibitor must be used.

3. Samples should be analyzed as soon as possible after collection.

4. If nitrogen trichloride or chlorine dioxide are present, special procedures are necessary.

H. Example

A sample taken after prechlorination at a filtration plant was tested for residual chlorine using the DPD Titrimetric Method.

mL of sample = 100 mL
Reading A, mL = 1.4 mL
Reading B, mL = 1.6 mL
Reading C, mL = 2.7 mL

I. Calculation

READING *CHLORINE RESIDUAL*

A = mg/L free residual chlorine
B-A = mg/L monochloramine
C-B = mg/L dichloramine
C-A = mg/L combined available chlorine
C = mg/L total residual chlorine

Example: The concentrations of the different types of residual chlorine present can be calculated from the information given in (H).

READING *CHLORINE RESIDUAL*

A = 1.4 mL = 1.4 mg/L free residual chlorine
B-A = 1.6-1.4 = 0.2 mg/L monochloramine
C-B = 2.7-1.6 = 1.1 mg/L dichloramine
C-A = 2.7-1.4 = 1.3 mg/L combined available chlorine
C = 2.7 mL = 2.7 mg/L total residual chlorine

J. Interpretation of Results

1. Any "chlorine" taste and odor that may result from chlorination would generally be from the dichloramine or nitrogen trichloride nuisance residuals.

2. Free residual chlorination produces the best results when the free residual makes up more than 80 percent of the total residual. However, this will not be the case if ammonia is added to the water being treated to form chloramines in order to prevent the formation of THMs.

K. Reference

See page 294, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 403.

7.3C List some of the important benefits of chlorinating water.

7.3D What is a potential adverse effect from chlorination?

3. Chlorine Demand

A. Discussion

The chlorine demand of water is the difference between the amount of chlorine applied (or dosed) and the amount of free, combined, or total residual chlorine remaining at the end of a specific contact period. The chlorine demand varies with the amount of chlorine applied, time of contact, pH and temperature. Also the presence of organics and reducing agents in water will influence the chlorine demand. The chlorine demand test should be conducted with chlorine gas or with granular hypochlorite, depending upon which form you usually use for chlorination.

The chlorine demand test can be used by the operator to determine the best chlorine dosage to achieve specific chlorination objectives. The measurement of chlorine demand is performed by treating a series of water samples in question with known but varying amounts of chlorine or hypochlorite. After the desired contact time, calculation of residual chlorine in the samples will demonstrate which dosage satisfied the requirements of the chlorine demand in terms of the residual desired.

B. What is Tested

	Common Range Chlorine Demand, mg/L
Surface	0.5 to 5
Well Water	0.1 to 1.3

C. Apparatus

In addition to the apparatus described under one of the methods for chlorine residual, the following items are required:

Flasks, Erlenmeyer (1000 mL)
Pipets (5 and 10 mL)
Graduated cylinder (500 mL)
Flask, volumetric (1000 mL)
Flask, Erlenmeyer (250 mL)
Buret (25 mL)

D. Reagents

In addition to the reagents described under the method you will use to determine chlorine residual, the following items are also needed:

1. Stock chlorine solution. Obtain a suitable solution from a chlorinator solution line or by purchasing a bottle of household bleach ("Chlorox" or similar product). Store in a dark, cool place to maintain chemical strength. Household bleach products usually contain approximately five percent available chlorine which is about 50,000 mg/L.

2. Chlorine dosing solution. If using household bleach, carefully pipet about 10 mL of the bleach into a 1000 mL volumetric flask. Fill to the mark with chlorine demand-free water and standardize. If using a stock chlorine solution obtained from a chlorinator solution line, simply standardize this solution directly.

   Standardization:

   a. Place 2 mL acetic acid and 20 mL chlorine demand-free water in a 250 mL flask.

   b. Add about 1 g KI crystals.

c. Measure into the flask a suitable volume of chlorine dosing solution. If using household bleach as your stock solution, add 25 m*L* of the dosing solution. Note: In measuring the volume of the dosing solution, notice that 1 m*L* of the 0.025 *N* thiosulfate titrant is equal to 0.9 mg chlorine.

d. Titrate with standardized 0.025 *N* thiosulfate titrant until the yellow iodine color almost disappears.

e. Add 1 to 2 m*L* starch indicator solution.

f. Continue to titrate until blue color disappears.

$$\text{mg}/L \text{ Cl as } Cl_2/\text{m}L = \frac{(\text{m}L \text{ thiosulfate used}) \times N \times 35.45}{\text{m}L \text{ of dosing solution}}$$

where N = normality of thiosulfate titrant

3. Acetic acid, concentrated (glacial).
4. Potassium Iodide, KI, crystals.
5. Standard sodium thiosulfate 0.025 *N*.
6. Chlorine-demand-free water. Prepare chlorine-demand-free water from good quality distilled or deionized water by adding sufficient chlorine to give 5 mg/*L* free chlorine residual. After standing 2 days, this solution should contain at least 2 mg/*L* free residual chlorine. If not, discard and obtain better quality water. Remove remaining free chlorine by placing the solution in the direct sunlight. After several hours, measure total chlorine residual. Do not use until last trace of chlorine has been removed.
7. Starch indicator.

E. Procedure

1. Measure a 500 m*L* sample into each of five to ten 1000 m*L* flasks or bottles.
2. To the first flask, add an amount of chlorine that leaves no residual at the end of the contact time. Mix.
3. Add increasing amounts of chlorine to successive portions of the sample and mix.
4. Measure residual chlorine after the specific contact time. Record results.
5. On graph paper, plot the residual chlorine (or the amount of chlorine consumed) versus chlorine dosage.

F. Precautions

1. Dose sample portions at time intervals that will leave you enough time for chlorine residual testing at predetermined contact times.
2. Conduct test over the desired contact time. If test objective is to duplicate your plant contact time, then match plant detention time as closely as possible.
3. Keep samples in the dark, protected from sunlight.
4. Temperature should be kept as constant as possible.
5. If test has bacteriologic objective, all glassware must be sterilized.

G. Example

A raw water sample was collected from a river to determine chlorine demand.

Contact time = 30 minutes (plant detention time)
pH = 7.6
Temperature = 15°C

Results from the chlorine demand test were as follows:

Flask No.	Chlorine Added, mg/*L*	Free Residual Chlorine after 30 min, mg/*L*
1	0.5	0.36
2	1.0	0.82
3	1.5	1.14
4	2.0	0.60
5	2.5	0.75
6	3.0	1.25

H. Calculation

Calculate the chlorine demand by using the formula

$$\text{Chlorine Demand, mg}/L = \text{Chlorine Added, mg}/L - \text{Free Residual Chlorine, mg}/L$$

Flask No.	Chlorine Added, mg/*L*	−	Free Residual Chlorine, mg/*L*	=	Chlorine Demand, mg/*L*
1	0.5	−	0.36	=	0.14
2	1.0	−	0.82	=	0.18
3	1.5	−	1.14	=	0.36
4	2.0	−	0.60	=	1.40
5	2.5	−	0.75	=	1.75
6	3.0	−	1.25	=	1.75

Valuable knowledge can be gained by plotting the data from test results. Figure 7.10 is a plot of the chlorine added vs. the free chlorine residual after 30 minutes. By drawing a smooth line between the plotting points, a typical breakpoint chlorination curve is produced.

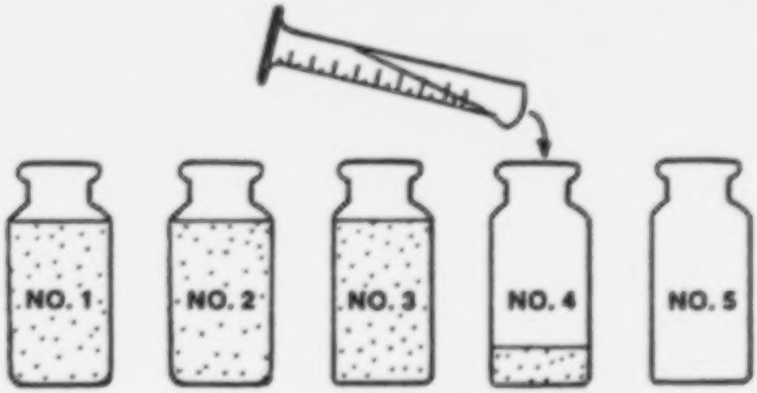
Figure 7.11 is a plot of the chlorine demand curve. Note that the far right end of the curge is flat which indicates that the chlorine demand has been satisfied. The curve reveals that the chlorine demand will increase as chlorine is added to water until you have gone past the breakpoint.

I. Reference

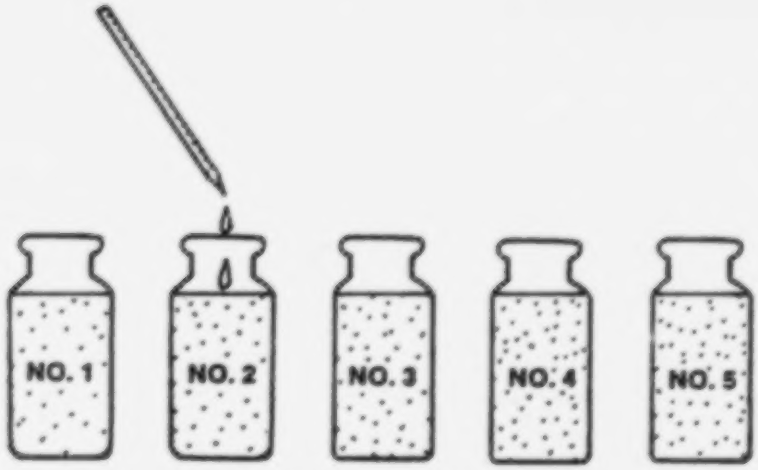
See page 316, *STANDARD METHODS*, 16th Edition.

(Chlorine Demand)

OUTLINE OF PROCEDURE


NO. 1
NO. 2
NO. 3
NO. 4
NO. 5

1. Measure 500 mL water sample to each container.


NO. 1
NO. 2
NO. 3
NO. 4
NO. 5

2. Add desired dosage of chlorine to each container.

3. After end of desired contact time, measure chlorine residual. Plot results on graph paper.

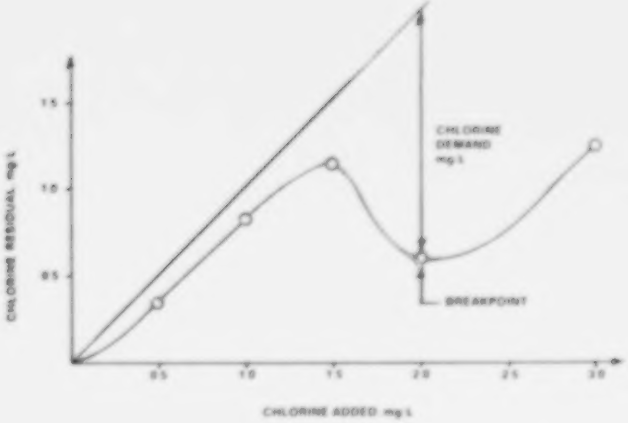


Fig. 7.10 *Breakpoint chlorination curve*

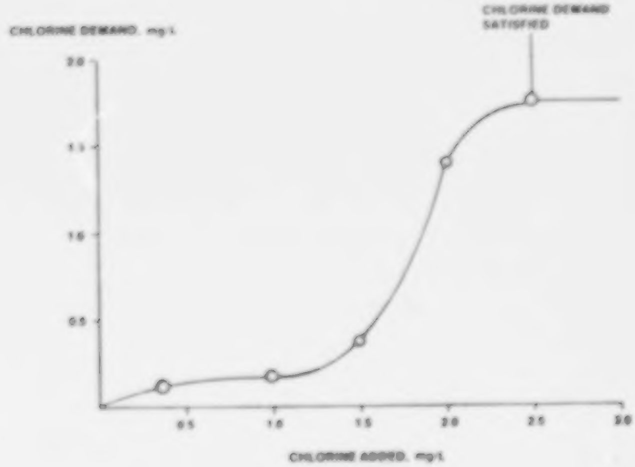


Fig. 7.11 Plot of chlorine demand on graph paper

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 403.

7.3E What conditions can cause variations in the chlorine demand?

7.3F How does the operator use the results from the chlorine demand test?

7.3G Calculate the chlorine demand for a raw water sample if chlorine is added at 2.0 mg/*L* and the free residual chlorine after 30 minutes was 0.4 mg/*L*.

End of Lesson 3 of 5 Lessons on LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. LABORATORY PROCEDURES

(Lesson 3 of 5 Lessons)

Write the answers to these questions in your notebook. The question numbering continues from Lesson 2.

12. What precautions must be taken with the sample when conducting the alkalinity test?
13. What could be the causes of tastes and odors that might result from chlorination?
14. What precautions should be exercised when performing a chlorine demand test?

CHAPTER 7. LABORATORY PROCEDURES

(Lesson 4 of 5 Lessons)

4. Coliform Bacteria

A. Discussion

An improperly treated or unprotected water supply may contain microorganisms that are pathogenic, that is capable of producing disease. Testing for specific pathogenic microorganisms (pathogens which cause diseases such as typhoid or dysentery) is very time-consuming and requires special techniques and equipment. So instead of testing for pathogens, water is generally analyzed for the presence of an "indicator organism," the coliform group of bacteria.

Coliform bacteria, or rather their absence, are a good index of the degree of bacteriologic safety of a water supply. In general, coliform bacteria can be divided into a fecal and a non-fecal group. Fecal coliform bacteria occur normally in the intestines of humans and other warm-blooded animals. They are discharged in great numbers in human and animal wastes. Coliforms are generally more hardy than true pathogenic bacteria and their absence from water is thus a good indication that the water is bacteriologically safe for human consumption. The presence of coliforms, however, indicates the potential presence of pathogenic organisms, that may have entered the water with them, and suggests that the water is not safe to drink.

The coliform group of bacteria includes all the aerobic and *FACULTATIVE*[10] anaerobic gram-negative, nonspore-forming rod-shaped bacteria that ferment lactose (a sugar) within 48 hours at 35°C (human body temperature). The fecal coliform can grow at a higher temperature (44.5°C) than the non-fecal coliform.

The bacteriological quality of water supplies is subject to control by federal, state, and local agencies, all of which are governed by the rules and regulations contained in the Safe Drinking Water Act. This law stipulates the methods to be used, the number of samples required, and the maximum levels allowed for coliform organisms in drinking water supplies. The number of samples required is generally based on population served by the water system. The maximum contaminant level (MCL) for coliforms is one organism per 100 *mL*. Operators should strive to produce finished water with zero coliforms.

B. Test Methods

Approved water testing procedures for total coliform bacteria are (1) the Multiple Tube Fermentation Method (sometimes called the Most Probable Number or MPN procedure) and (2) the Membrane Filter (MF) Method.

1. Multiple Tube Fermentation Method (MPN)

The multiple tube coliform test has been a standard method for determining the coliform group of bacteria since 1936. In this procedure tubes of lauryl tryptose broth are inoculated with a water sample. Lauryl tryptose broth contains lactose which is the source of carbohydrates (sugar). The coliform density is then calculated from statistical probability formulas that predict the most probable number (MPN) of coliforms in a 100 *mL* sample necessary to produce certain combinations of "gas-positive" (gas forming) and gas-negative tubes in the series of inoculated tubes.

There are three distinct test states for coliform testing using the Multiple Tube Fermentation Method — the Presumptive Test, the Confirmed Test, and the Completed Test. Each test makes the coliform test more valid and specific. These tests are described in detail in the following paragraphs.

2. Membrane Filter (MF) Method

This method was introduced as a tentative method in 1955 and has been an approved test for coliform bacteria since 1960. The basic procedure involves filtering a known volume of water through a membrane filter of optimum pore size for full coliform bacteria retention. As the water passes through the microscopic pores, bacteria are entrapped on the upper surface of the filter. The membrane filter is then placed in contact with either a paper pad saturated with liquid medium or directly over an agar (gelatin-like) medium to provide proper nutrients for bacterial growth. Following incubation under prescribed conditions of time, temperature, and humidity, the cultures are examined for coliform colonies that are counted directly and recorded as a density of coliform per 100 *mL* of water sample.

There are certain important limitations to membrane filter methods. Some types of samples cannot be filtered because of excessive turbidity, high non-coliform bacterial densities, or heavy-metal (bactericidal) compounds. In addition, coliforms contained in chlorinated supplies sometimes do not give characteristic reactions on the media and hence special procedures must then be used.

C. What is Tested

	Common Range Total Coliform per 100 *mL*
Surface waters	50 to 1,000,000
Treated water supplies	0
Well water	0 to 50

D. Materials Required

1. Sampling Bottles

Bottles of glass or other material which are watertight, resistant to the solvent action of water and capable of being sterilized may be used for bacteriologic sampling. Plastic bottles made of nontoxic materials are also satisfactory and eliminate the possibility of breakage during transport. The bottles should hold a sufficient volume of sample for all tests, permit proper washing, and maintain the samples uncontaminated until examinations are complete.

Before sterilization by autoclave, add 0.1 *mL* 10 percent sodium thiosulfate per 4 ounce bottle (120 *mL*). This will neutralize a sample containing about 15 mg/*L* residual chlorine. If the residual chlorine is not neutralized, it would continue to be toxic to the coliform organisms remaining in the sample and give false results.

---

[10] *Facultative (FACK-ul-tay-tive). Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.*

When filling bottles with sample, do not flush out sodium thiosulfate or contaminate bottle or sample. Fill bottles approximately three-quarters full and start test in laboratory within six hours. If the samples cannot be processed within one hour, they should be held below 10°C for not longer than six hours.

2. Glassware

All glassware must be thoroughly cleansed using a suitable detergent and hot water (160°F or 71°C), rinsed with hot water (180°F or 82°C) to remove all traces of residual detergent, and finally rinsed with distilled or deionized water.

3. Water

Only distilled water or demineralized water which has been tested and found free from traces of dissolved metals and bactericidal and inhibitory compounds may be used for preparation of culture media.

4. Buffered[11] Dilution Water

Prepare a stock solution by dissolving 34 grams of KH_2PO_4 in 500 *mL* distilled water, adjusting the pH to 7.2 with 1 *N* NaOH and dilute to one liter. Prepare dilution water by adding 1.25 *mL* of the stock solution and 5.0 *mL* magnesium sulfate (50 grams $MgSO_4 \cdot 7\,H_2O$ dissolved in one liter of water) to 1 liter distilled water. This solution can be dispersed into various size dilution blanks or used as a sterile rinse for the membrane filter test.

5. Media Preparation

Careful media preparation is necessary for meaningful bacteriological testing. Attention must be given to the quality, mixing, and sterilization of the ingredients. The purpose of this care is to assure that if the bacteria being tested for are indeed present in the sample, every opportunity is presented for the development and ultimate identification. Much bacteriological identification is done by noting changes in the medium; consequently, the composition of the medium must be standardized. Much of the tedium of media preparation can be avoided by purchase of dehydrated media (Difco, BBL, or equivalent) from local scientific supply houses. The operator is advised to make use of these products; and, if only a limited amount of testing is to be done, consider using tubed, prepared media.

MEDIA — MPN (TOTAL COLIFORM)

a. Lauryl Tryptose Broth

For the Presumptive Coliform Test, dissolve the recommended amount of the dehydrated media in distilled water. Dispense solution into fermentation tubes containing an inverted glass vial (see illustration of the tube with vial on page 384). For 10 *ML* water portions from samples, double-strength media is required while all other inoculations require single strength. Directions for preparation are given on the media bottle label.

b. Brilliant Green Bile Broth

For the Confirmed Coliform Test, dissolve 40 grams of the dehydrated media in one liter of distilled water. Dispense and sterilize as with Lauryl Tryptose Broth.

MEDIA — MEMBRANE FILTER METHOD (TOTAL COLIFORM)

a. M-Endo Broth

Prepare this media by dissolving 48 grams of the dehydrated product in one liter of distilled water which contains 20 *mL* of ethyl alcohol[12] per liter. Heat solution to boiling only — *DO NOT AUTOCLAVE.* Promptly remove solution from heat and cool. Prepared media should be stored in a refrigerator and used within 96 hours.

b. LES Endo Agar

Prepare this media, used for the two-step procedure, as per instructions found on the bottle.

6. Media Storage

Culture media should be prepared in batches of such size that the entire batch will be used in less than one week.

7. Autoclaving

Steam autoclaves are used for the sterilization of the liquid media and associated apparatus. They sterilize (killing of all organisms) at a relatively low temperature of 121°C within 15 minutes by utilizing moist heat.

Components of the media, particularly sugars such as lactose, may decompose at higher temperatures or longer heating times. For this reason adherence to time and temperature schedules is vital. The maximum elapsed time for exposure of the medium to any heat (from the time the autoclave door is closed to unloading) is 45 minutes. Preheating the autoclave can reduce total heating time.

Autoclaves operate in a manner similar to the familiar kitchen pressure cooker:

a. Water is heated in a boiler to produce steam.

b. The steam is vented to drive out air.

c. The steam vent is closed when the air is gone.

---

[11] *Buffer. A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.*

[12] *In some states the ethyl alcohol used in bacteriological media preparation CANNOT be the specially denatured alcohol sold by supply houses to people without an alcohol permit. One way to obtain suitable ethanol under these circumstances is to buy a brand of ethanol sold for human consumption.*

(Coliform)

d. Continued heat raises the pressure to 15 lbs/sq in (103.4 k Pa or 1.05 kg/sq cm); (at this pressure, pure steam has a temperature of 121°C at sea level only).

e. The heat and pressure are maintained for 15 minutes.

f. The heat is turned off.

g. The steam vent is opened to slowly vent steam until atmospheric pressure is reached. (Fast venting will cause the liquids to boil and overflow tubes.)

h. Sterile material is removed to cool.

In autoclaving fermentation tubes, a vacuum is formed in the inner tubes. As the tubes cool, the inner tubes are filled with sterile medium. Capture of gas in this inner tube from the culture of bacteria is the evidence of fermentation and is recorded as a *POSITIVE TEST.*

E. Procedure for Testing Total Coliform Bacteria

Multiple Tube Fermentation Method

1. *GENERAL DISCUSSION*

Coliform bacteria are detected in water by placing portions of a sample of the water in lauryl tryptose broth. Lauryl tryptose broth is a standard bacteriological media containing lactose (milk) sugar in tryptose broth. The coliform bacteria are those which can grow in this media at 35°C temperature and are able to ferment and produce gas from the lactose within 48 hours. Thus, to detect these bacteria the operator need only inspect the fermentation tubes for gas. A schematic of the coliform test procedure is shown in Figure 7.12.

2. *MATERIALS NEEDED*

FOR UNTREATED WATER SAMPLES

a. Fifteen sterile tubes containing 10 mL of lauryl tryptose broth are needed for each sample. Use five tubes for each dilution.

b. Dilution tubes or blanks containing 99 mL of sterile buffered distilled water.

c. A quantity of 1 mL and 10 mL serological pipets. The 1 mL pipets should be graduated in 0.1 mL.

d. Incubator set at 35 ± 0.5°C.

e. Thermometer verified to be accurate by comparison with a National Bureau of Standards (NBS) certified thermometer.

FOR DRINKING WATER SAMPLES

a. Five sterile tubes of 10 mL double-strength lauryl tryptose broth are needed if 10 mL of sample is added to each tube. Ten mL of lauryl tryptose broth is required in all tubes containing one mL or less of sample.

b. Sterile 10 mL pipe for each sample.

c. Incubator set at 35 ± 0.5°C.

d. Thermometer verified to be accurate by comparison with a National Bureau of Standards (NBS) certified thermometer, or equivalent.

3. Technique for Inoculation of Sample (Figures 7.13 and 7.14).

All inoculations and dilutions of water samples must be accurate and made so that no contaminants from the air, equipment, clothes or fingers reach the sample, either directly or by way of a contaminated pipet. Clean, sterile pipets must be used for each separate sample.

FOR UNTREATED WATER SAMPLES

a. Shake the sample bottle vigorously 20 times before removing sample volumes.

b. Pipet 10 mL of sample directly into each of the first five tubes. Each tube must contain 10 mL lauryl tryptose broth (double strength).

NOTE: You must realize that the sample volume applied to the first five tubes will depend upon the type of water being tested. The sample volume applied to each tube can vary from 10 mL for high quality waters to as low as 0.00001 mL (applied as 1 mL of a diluted sample) for highly polluted raw water samples.

NOTE: When delivering the sample into the culture medium, deliver sample portions of 1 mL or less down into the culture tube near the surface of the medium. *DO NOT* deliver small sample volumes at the top of the tube and allow them to run down inside the tube; too much of the sample will fail to reach the culture medium.

NOTE: Use 10 mL pipets for 10 mL sample portions, and 1 mL pipets for portions of 1 mL or less. Handle sterile pipet only near the mouthpiece, and protect the delivery end from external contamination.

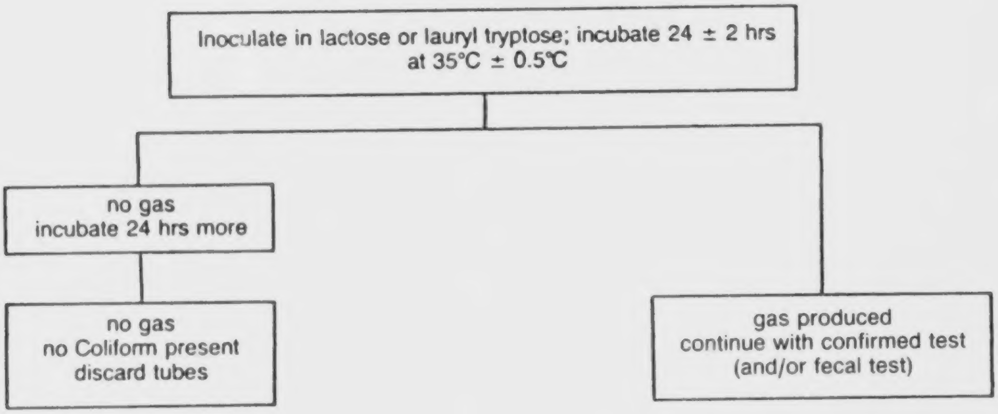
c. Pipet 1 mL of water sample into each of the next five lauryl tryptose broth (single strength) tubes.

d. Pipet 1/10 mL (0.1 mL) of water sample into each of the next five lauryl tryptose broth (single strength) tubes. This makes a 0.1 (1 to 10) dilution.

At this point you have 15 tubes inoculated and can place these three sets of tubes in the incubator; however, your sample specimen may show gas production in all fermentation tubes. This means your sample was not diluted enough and you have no usable results.

TOTAL COLIFORM

1. Presumptive Test


Inoculate in lactose or lauryl tryptose; incubate 24 ± 2 hrs at 35°C ± 0.5°C
no gas incubate 24 hrs more
no gas no Coliform present discard tubes
gas produced continue with confirmed test (and/or fecal test)

2. Confirmed Test

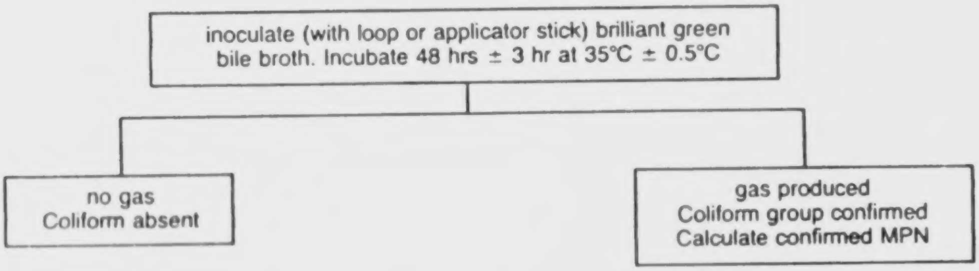

inoculate (with loop or applicator stick) brilliant green bile broth. Incubate 48 hrs ± 3 hr at 35°C ± 0.5°C
no gas Coliform absent
gas produced Coliform group confirmed Calculate confirmed MPN

Fig. 7.12 Schematic outline of test procedure for Total Coliform — Multiple Tube Fermentation Method

(Coliform)

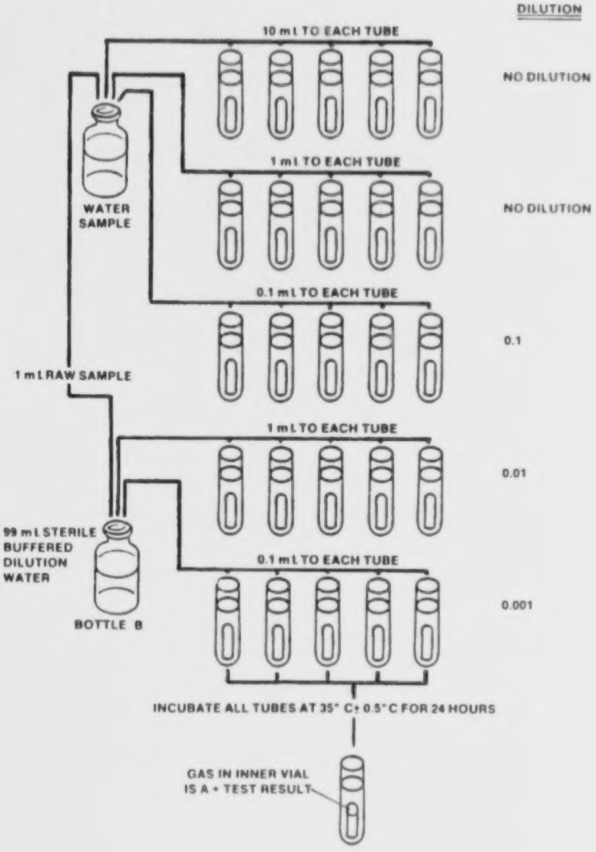

DILUTION
10 mL TO EACH TUBE
NO DILUTION
1 mL TO EACH TUBE
NO DILUTION
WATER SAMPLE
0.1 mL TO EACH TUBE
0.1
1 mL RAW SAMPLE
1 mL TO EACH TUBE
0.01
99 mL STERILE BUFFERED DILUTION WATER
BOTTLE B
0.1 mL TO EACH TUBE
0.001
INCUBATE ALL TUBES AT 35° C ± 0.5° C FOR 24 HOURS
GAS IN INNER VIAL IS A + TEST RESULT

Fig. 7.13 Coliform bacteria test — raw water

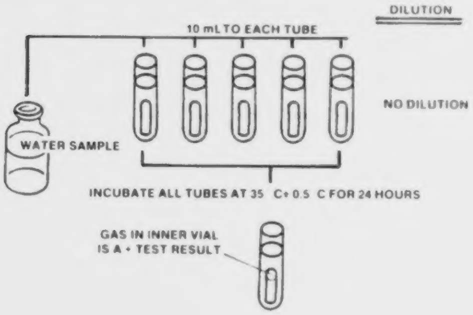

DILUTION
10 mL TO EACH TUBE
NO DILUTION
WATER SAMPLE
INCUBATE ALL TUBES AT 35° C ± 0.5° C FOR 24 HOURS
GAS IN INNER VIAL IS A + TEST RESULT

Fig. 7.14 Coliform bacteria test — drinking water

e. To make a 1/100 (0.01) dilution, add 1 m*L* of well mixed water sample to 99 m*L* of sterile buffered dilution water. Mix thoroughly by shaking. Add 1 m*L* from this bottle directly into each of five more lauryl tryptose broth tubes.

f. To make a 1/1000 (0.001) dilution, add 0.1 m*L* from the 1/100 dilution bottle directly into each of five more lauryl tryptose broth tubes.

The first time a sample is analyzed, twenty-five tubes of lauryl tryptose broth should be prepared. Once you find out what dilutions give usable results for determining the MPN index, you will only need to prepare fifteen tubes to analyze subsequent samples from the same source.

FOR DRINKING WATER SAMPLES

a. Shake the sample bottle vigorously twenty times before removing a sample volume.

b. Pipet 10 m*L* of sample directly into each of five tubes containing 10 m*L* of double-strength lauryl tryptose broth.

4. Incubation (Total Coliform)

a. 24-Hour Lauryl Tryptose (LT) Broth Presumptive Test

Place all inoculated LT broth tubes in 35°C ± 0.5°C incubator. After 24 ± 2 hours have elapsed, examine each tube for gas formation in inverted vial (inner tube). Mark plus (+) on report form such as shown in Figure 7.15 for all tubes that show presence of gas. Mark minus (−) for all tubes showing no gas formation. Immediately perform Confirmation Test on all positive (+) tubes (see Section C, BGB Confirmation Test). The negative (−) tubes must be reincubated for an additional 24 hours.

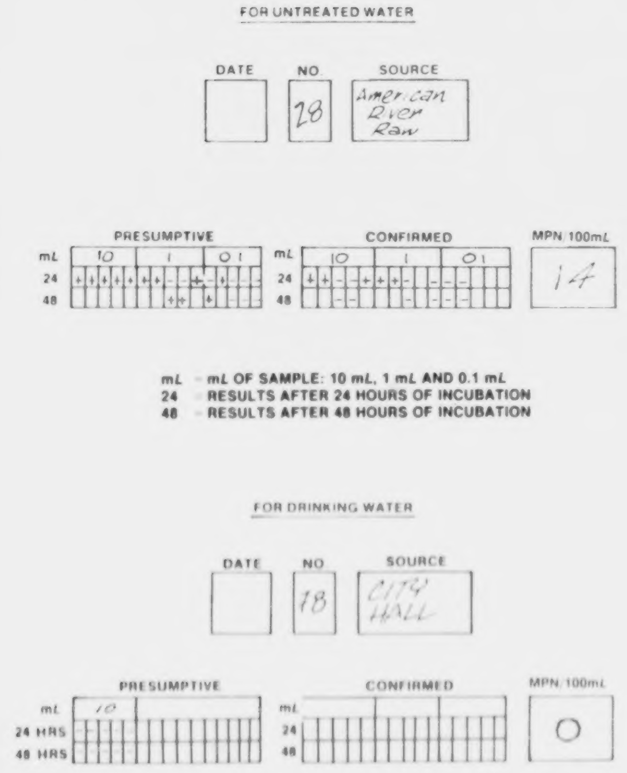
b. 48-Hour Lauryl Tryptose Broth Presumptive Test

Record both positive and negative tubes at the end of 48 ± 3 hours. Immediately perform Confirmation Test on all new positive tubes.

c. 24-Hour Brilliant Green Bile (BGB) Confirmation Test

Confirm all presumptive tubes that show gas at 24 or 48 hours. Transfer, with the aid of a sterile 3 mm platinum wire loop (sterile wood applicator or disposable loops may be used also), one loop-full of the broth from the lauryl tryptose broth tubes showing gas, and inoculate a corresponding tube of BGB (Brilliant Green Bile) broth by mixing the loop of broth in the BGB broth. Discard all positive lauryl tryptose broth tubes after transferring is completed.

Always sterilize inoculation loops and needles in flame immediately before transfer of culture; do not lay loop down or touch it to any nonsterile object before making the transfer. After sterilization in a flame, allow sufficient time for cooling, in the air, to prevent the heat of the loop from killing the bacterial cells being transferred. Wooden sterile applicator sticks also are used to transfer cultures, especially in the field where a flame is not available for sterilization. If using hardwood applicators, sterilize by autoclaving before use and discard after each transfer.


FOR UNTREATED WATER

DATE:
NO.: 28
SOURCE: American River Raw

MPN/100mL: 14

PRESUMPTIVE
CONFIRMED
mL
10
1
0.1
24
48

mL = mL OF SAMPLE: 10 mL, 1 mL AND 0.1 mL
24 = RESULTS AFTER 24 HOURS OF INCUBATION
48 = RESULTS AFTER 48 HOURS OF INCUBATION

FOR DRINKING WATER

DATE:
NO: 18
SOURCE: CITY HALL

MPN/100mL: 0

PRESUMPTIVE
mL
10
24 HRS
48 HRS
CONFIRMED
mL
24
48

Fig. 7.15 Recorded coliform test results

After 24 hours have elapsed, inspect each of the BGB tubes for gas formation. Those with any amount of gas are considered positive and are so recorded on the data sheet. Negative BGB tubes are reincubated for an additional 24 hours.

d. 48-Hour Brilliant Green Bile Confirmation Test

(1) Examine tubes for gas at the end of the 48 ± 3 hour period. Record both positive and negative tubes.

(2) Complete reports by determining MPN Index and recording MPN on work sheets.

5. Recording Results

Results should be recorded on data sheets prepared especially for this test. Examples are shown in Figure 11.15.

6. Method of Calculating the Most Probable Number (MPN)
Select the highest dilution or inoculation with all positive tubes, before a negative tube occurs, plus the next two dilutions.

(Coliform)

EXAMPLE NO. 1 (UNTREATED WATER) — Select the underlined inoculations.

mL of sample	10	1	0.1	0.01	0.001
dilutions	0	0	−1	−2	−3
positive tubes	5	1	0	0	0

Read MPN as	33 per 100 mL from Table 11.3
Report MPN as	33 per 100 mL

EXAMPLE NO. 2 (UNTREATED WATER) —
Select the underlined inoculations (see Figure 11.16).

mL of sample	10	1	0.1	0.01	0.001
dilutions	0	0	−1	−2	−3
positive tubes	5	5	2	0	0

Read MPN as	49 per 100 mL from Table 11.3
Report results as	490/100 mL

We added one zero to 49 because we started with the 1 mL sample and Table 7.3 begins with one dilution column to the left.

For Example No. 2

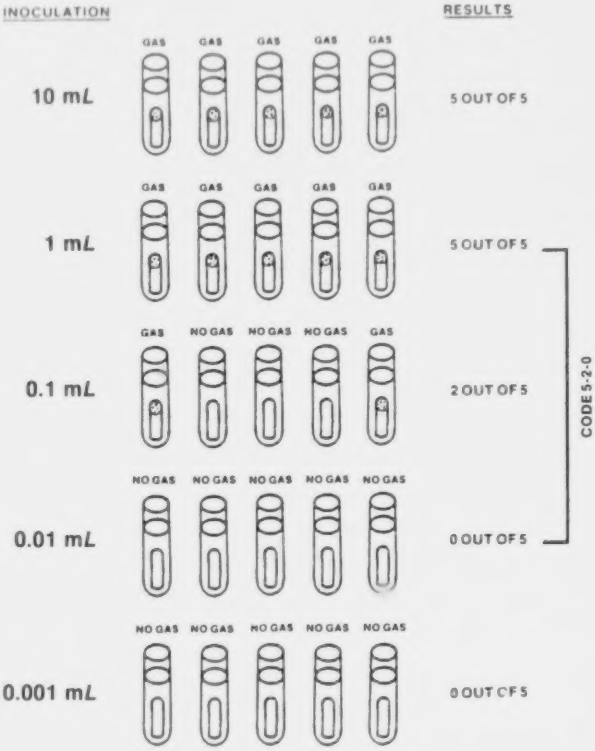

INOCULATION
RESULTS
10 mL
GAS
GAS
GAS
GAS
GAS
5 OUT OF 5
1 mL
GAS
GAS
GAS
GAS
GAS
5 OUT OF 5
0.1 mL
GAS
NO GAS
NO GAS
NO GAS
GAS
2 OUT OF 5
0.01 mL
NO GAS
NO GAS
NO GAS
NO GAS
NO GAS
0 OUT OF 5
0.001 mL
NO GAS
NO GAS
NO GAS
NO GAS
NO GAS
0 OUT OF 5
CODE 5-2-0

Fig. 7.16 Results of coliform test — untreated water

(Coliform)

TABLE 7.3

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-mL, FIVE 1-mL AND FIVE 0.1-mL PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-mL portions	Five 1-mL portions	Five 0.1-mL portions	(organisms per 100 mL)
0	0	0	0
0	0	1	2
0	0	2	4
0	1	0	2
0	1	1	4
0	1	2	5
0	2	0	4
0	2	1	6
0	3	0	6
1	0	0	2
1	0	1	4
1	0	2	6
1	0	3	8
1	1	0	4
1	1	1	6
1	1	2	8
1	2	0	6
1	2	1	8
1	2	2	10
1	3	0	8
1	3	1	10
1	4	0	11
2	0	0	5
2	0	1	7
2	0	2	9
2	0	3	12
2	1	0	7
2	1	1	9
2	1	2	12
2	2	0	9
2	2	1	12
2	2	2	14
2	3	0	12
2	3	1	14
2	4	0	15
3	0	0	8
3	0	1	11
3	0	2	13
3	1	0	11
3	1	1	14
3	1	2	17
3	1	3	20
3	2	0	14
3	2	1	17
3	2	2	20
3	3	0	17
3	3	1	21

TABLE 7.3 (Cont.)

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-m*L*, FIVE 1-m*L* AND FIVE 0.1-m*L* PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-m*L* portions	Five 1-m*L* portions	Five 0.1-m*L* portions	(organisms per 100 m*L*)
3	4	0	21
3	4	1	24
3	5	0	25
4	0	0	13
4	0	1	17
4	0	2	21
4	0	3	25
4	1	0	17
4	1	1	21
4	1	2	26
4	2	0	22
4	2	1	26
4	2	2	32
4	3	0	27
4	3	1	33
4	3	2	39
4	4	0	34
4	4	1	40
4	5	0	41
4	5	1	48
5	0	0	23
5	0	1	30
5	0	2	40
5	0	3	60
5	0	4	80
5	1	0	30
5	1	1	50
5	1	2	60
5	1	3	80
5	2	0	50
5	2	1	70
5	2	2	90
5	2	3	130
5	2	4	150
5	2	5	180
5	3	0	80
5	3	1	110
5	3	2	140
5	3	3	170
5	3	4	210
5	3	5	250
5	4	0	130
5	4	1	170
5	4	2	220
5	4	3	280

TABLE 7.3 (Cont.)

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-m*L*, FIVE 1-m*L* AND FIVE 0.1-m*L* PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-m*L* portions	Five 1-m*L* portions	Five 0.1-m*L* portions	(organisms per 100 m*L*)
5	4	4	350
5	4	5	430
5	5	0	240
5	5	1	300
5	5	2	500
5	5	3	900
5	5	4	1600
5	5	5	≥1600

EXAMPLE NO. 3 (DRINKING WATER SAMPLE) — (see Figure 7.17)

m*L* of sample	10
positive tubes	1
Read MPN as	2.2 per 100 m*L* from Table 11.4

For Example No. 3

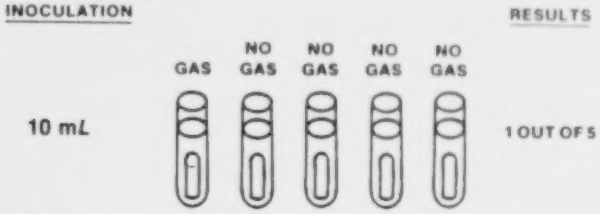


Figure 7.17 Results of coliform test — drinking water

TABLE 7.4

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS WHEN FIVE 10 m*L* PORTIONS ARE USED

Number of tubes giving positive reaction out of 5 of 10 m*L* each	MPN Index per 100 m*L*
0	less than 2.2
1	2.2
2	5.1
3	9.2
4	16
5	greater than 16

When you wish to summarize with a single MPN value the results from a series of samples, the arithmetic mean, the median, or the geometric mean may be used (see following sections for *FORMULAS* and *EXAMPLES*).

FORMULAS

The MPN for combinations not appearing in the table given or for other combinations of tubes or dilutions may be estimated by the formula:

$$\text{MPN/100 m}L = \frac{(\text{No. of positive tubes})\,(100)}{\sqrt{\begin{pmatrix}\text{m}L\text{ sample in}\\ \text{negative tubes}\end{pmatrix} \times \begin{pmatrix}\text{m}L\text{ sample in}\\ \text{all tubes}\end{pmatrix}}}$$

Coliform results may be summarized with a single MPN value by using the arithmetic mean, median, or geometric mean. The arithmetic mean is often called the average.

$$\text{Mean} = \frac{\text{Sum of items or values}}{\text{Number of items or values}}$$

The median is the middle value in a set or group of data. There are just as many values larger than the median as there are smaller than the median. To determine the median, the data should be written in ascending (increasing) or descending (decreasing) order and the middle value identified.

Median = Middle value of a group of data

The median and geometric mean are used when a sample contains a few very large values. This frequently happens when measuring the MPN of raw water. If **X** is a measurement (MPN) and **n** is the number of measurements, then

$$\text{Geometric Mean} = [(X_1)(X_2)(X_3)\ \ldots\ldots\ldots\ldots\ (X_n)]^{1/n}$$

This calculation can be easily performed on many electronic calculators

EXAMPLE 4

The results from an MPN test using five fermentation tubes for each dilution on a sample of water were as follows:

Sample Size, m*L*	10	1.0	0.1
Number of Positive Tubes Out of Five Tubes	3+	1+	0+

Determine the information necessary to solve the formula:

$$\text{MPN/100 mL} = \frac{(\text{No. of positive tubes})\ (100)}{\sqrt{\begin{pmatrix}\text{mL sample in}\\ \text{negative tubes}\end{pmatrix} \times \begin{pmatrix}\text{mL sample in}\\ \text{all tubes}\end{pmatrix}}}$$

1. Number of positive tubes. There were 3 positive tubes with 10 mL of sample and 1 positive tube with 1 mL of sample. Therefore, 3 + 1 = 4 positive tubes.

2. Determine the mL of sample in negative tubes.

Sample Size, mL	Number of Negative Tubes	mL of Sample in Negative Tubes	
10 mL	2	(10 mL)(2)	= 20 mL
1.0mL	4	(1.0 mL)(4)	= 4 mL
0.1 mL	5	(0.1 mL)(5)	= 0.5 mL
		Total	= 24.5 mL

3. Determine the mL of sample in all tubes.

Sample Size, mL	Number of Tubes	mL of Sample in All Tubes	
10 mL	5	(10 mL)(5)	= 50 mL
1.0 mL	5	(1.0 mL)(5)	= 5 mL
0.1 mL	5	(0.1 mL)(5)	= 0.5 mL
		Total	= 55.5 mL

4. Estimate the MPN/100 mL.

$$\text{MPN/100 mL} = \frac{(\text{No. of positive tubes})\ (100)}{\sqrt{\begin{pmatrix}\text{mL sample in}\\ \text{negative tubes}\end{pmatrix} \times \begin{pmatrix}\text{mL sample in}\\ \text{all tubes}\end{pmatrix}}}$$

$$= \frac{(4)(100)}{\sqrt{(24.5\ \text{mL})(55.5\ \text{mL})}}$$

$$= \frac{400}{36.87}$$

$$= 10.8\ \text{MPN Coliforms/100 mL}$$

$$= 11\ \text{MPN Coliforms/100 mL}$$

EXAMPLE 5

Results from MPN tests during one week were as follows:

Day	S	M	T	W	TH	F	S
MPN/100 mL	2	8	14	5	10	26	4

Estimate the (1) mean, (2) median, and (3) geometric mean of the data in MPN/100 mL.

1. Calculate the mean.

$$\text{Mean, MPN/100 mL} = \frac{\text{Sum of All MPNs}}{\text{Number of MPNs}}$$

$$= \frac{2+8+14+6+10+26+4}{7}$$

$$= \frac{70}{7}$$

$$= 10\ \text{MPN/100 mL}$$

2. To determine the median, rearrange the data in ascending (increasing) order and select the middle value (three will be smaller and three will be larger in this example).

Order	1	2	3	4	5	6	7
MPN/100 mL	2	4	6	8 ↑	10	14	26

Median, MPN/100 mL = Middle value of a group of data
= 8 MPN/100 mL

3. Calculate the geometric mean for the given data.

$$\text{Geometric Mean, MPN/100 mL} = [(X_1)(X_2)(X_3)(X_4)(X_5)(X_6)(X_7)]^{1/7}$$

$$= [(2)(8)(14)(6)(10)(26)(4)]^{1/7}$$

$$= [1{,}397{,}760]^{1/7}$$

$$= 7.5\ \text{MPN/100 mL}$$

4. *SUMMARY*

1. Mean = 10 MPN/100 mL
2. Median = 8 MPN/100 mL
3. Geometric Mean = 7.5 MPN/100 mL

As you can see from the summary, the geometric mean more nearly describes most of the MPNs. This is the reason why the geometric mean is sometimes used to describe the results of MPN tests when there are a few very large values.

Membrane Filter Method

1. *GENERAL DISCUSSION*

In addition to the fermentation tube test for coliform bacteria, another test is used for these same bacteria in water analysis. This test uses a cellulose ester filter, called a membrane filter, the pore size of which can be manufactured to close tolerances. Not only can the pore size be made to selectively trap bacteria from water filtered through the membrane, but nutrients can be diffused (from an enriched pad) through the membrane to grow these bacteria into colonies. These colonies are recognizable as coliform because the nutrients include fuchsin dye which peculiarly colors the colony. Knowing the number of colonies and the volume of water filtered, the operator can then compare the water tested with water quality standards.

A two step pre-enrichment technique is included at the end of this section for samples which have been chlorinated. Chlorinated bacteria which are still living have had their enzyme systems damaged and require a 2-hour enrichment media before contact with the selective M-Endo Media.

2. *MATERIALS NEEDED*

a. One sterile membrane filter having a 0.45μ pore size.

b. One sterile 47 mm petri dish with lid.

c. One sterile funnel and support stand.

d. Two sterile pads.

e. One receiving flask (side-arm, 1000 mL).

f. Vacuum pump, trap, suction or vacuum gage, connection sections of plastic tubing, glass "T" hose clamp to adjust pressure bypass.

g. Forceps (round-tipped tweezers), alcohol, Bunsen Burner, grease pencil.

h. Sterile buffered distilled water for rinsing.

i. M-Endo Media.

j. Sterile pipets — two 5 mL graduated pipets and one, 1-mL pipet for sample or one 10-mL pipet for larger sample. Quantity of one-mL pipets if dilution of sample is necessary. Also, quantity of dilution water blanks if dilution of sample is necessary.

k. One moist incubator at 35°C; auxiliary incubator dish with cover.

l. Enrichment media — lauryl tryptose broth (for pre-enrichment technique).

m. A binocular wide-field dissecting microscope is recommended for counting. The light source should be a cool white fluorescent lamp.

3. *SELECTION OF SAMPLE SIZE*

Size of the sample will be governed by the expected bacterial density. An ideal quantity will result in the growth of between 20 to 80 coliform colonies, but not more than 200 bacterial colonies of all types. The table below lists suggested sample volumes for MF total coliform testing.

	Quantities Filtered (mL)				
	100	10	1	0.1	0.01
Well Water	x				
Drinking Water	x				
Lakes	x	x	x		
Rivers		x	x	x	x

When less than 20 mL of sample is to be filtered, a small amount of sterile dilution water should be added to the funnel before filtration. This increase in water volume aids in uniform dispersion of the sample over the membrane filter.

4. *PREPARATION OF PETRI DISH FOR MEMBRANE FILTER*

a. Sterilize forceps by dipping in alcohol and passing quickly through Bunsen burner flame to burn off the alcohol. An alcohol burner may be used also.

b. Place sterile absorbent pad into sterile petri dish.

c. Add 1.8 to 2.0 mL M-Endo Medium to absorbent pad using a sterile pipet. Remove excess media.

5. *PROCEDURE FOR FILTRATION OF UNCHLORINATED SAMPLES*

All filtrations and dilutions of water specimens must be accurate and should be made so that no contaminants from the air, equipment, clothes or fingers reach the specimen either directly or by way of the contaminated pipet.

a. Secure tubing from pump and bypass to receiving flask. Place palm of hand on flask opening and start pump. Adjust suction to ¼ atmosphere with hose clamp on pressure bypass. Turn pump switch to OFF.

b. Set sterile filter-support-stand and funnel on receiving flask. Loosen wrapper. Rotate funnel counterclockwise to disengage pin. Recover with wrapper.

c. Place petri dish on bench with lid up. Write identification on lid with grease pencil.

d. Unwrap sterile pad container. Light Bunsen burner.

e. Unwrap membrane filter container.

f. Sterilize forceps by dipping in alcohol and passing quickly through Bunsen burner to burn off the alcohol.

g. Center membrane filter on filter stand with forceps after lifting funnel. Membrane filter with printed grid should show grid uppermost (Fig. I, next page).

h. Replace funnel and lock against pin (Fig. II).

i. Shake sample or diluted sample. Measure proper *ALIQUOT*[13] with sterile pipet and add to funnel.

j. Add a small amount of the sterile dilution water to funnel. This will help check for leakage and also aid in dispersing small volumes (Fig. III).

k. Now start vacuum pump.

l. Rinse filter with three 20- to 30-mL portions of sterile dilution water.

m. When membrane filter appears barely moist, switch pump to OFF.

n. Sterilize forceps as before.

o. Remove membrane filter with forceps after first removing funnel as before (Fig. I).

p. Center membrane filter on pad containing M-Endo Media with a rolling motion to insure water seal. Inspect membrane to insure no captured air bubbles are present (Fig. IV).

q. Place *INVERTED* petri dish in incubator for 22 ± 2 hours. Incubate at 35°C.

6. *PROCEDURE FOR COUNTING MEMBRANE FILTER COLONIES*

a. Remove petri dish from incubator.

b. Remove lid from petri dish.

c. Turn so that your back is to window.

d. Tilt membrane filter in base of petri dish so that green and yellow-green colonies are most apparent. Direct sunlight has too much red to facilitate counting.

e. Count individual colonies utilizing an overhead fluorescent light. Use a low power (10 to 15 magnifications) binocular widefield dissecting microscope or similar optical device. The typical colony has a pink to dark red color with a metallic surface sheen. The sheen area may vary from a small pin-head size to complete coverage of the colony surface. Only those showing this sheen should be counted.

f. Report total number of "coliform colonies" on work sheet. Use the membranes that show from 20 to 90 colonies and do not have more than 200 colonies of all types (including non-sheen or, in other words, non-coliforms).

EXAMPLE:

A total of 42 colonies grew after filtering a 10 mL sample.

$$\text{Bacteria/100 mL} = \frac{\text{No. of colonies counted} \times 100\text{ mL}}{\text{Sample volume filtered, mL} \times 100\text{ mL}}$$

$$= \frac{(42\text{ colonies})\,(100\text{ mL})}{(10\text{ mL})\,(100\text{ mL})}$$

$$= \frac{(4.2)\,(100\text{ mL})}{100\text{ mL}}$$

$$= 420\text{ per }100\text{ mL}$$

SPECIAL NOTE:

Inexperienced persons often have great difficulty with connected colonies, with mirror reflections of fluorescent tubes (which are confused with metallic sheen), and with water condensate and particulate matter which are occasionally mistaken for colonies. Thus there is a

---

[13] *Aliquot (AL-li-kwot) Portion of sample.*

OUTLINE OF PROCEDURE FOR INOCULATION OF MEMBRANE FILTER

Fig. I

1. Center membrane filter on filter holder. Handle membrane only on outer $^{3}/_{16}$ inch with forceps sterilized before use in ethyl or methyl alcohol and passed lightly through a flame.

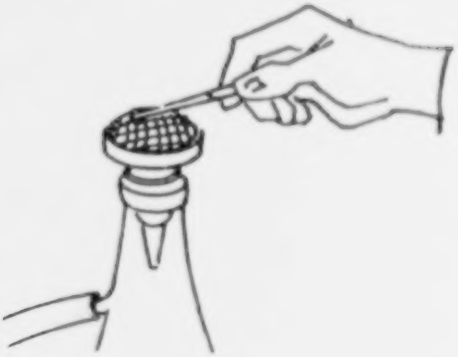


Fig. II

2. Place funnel onto filter holder.

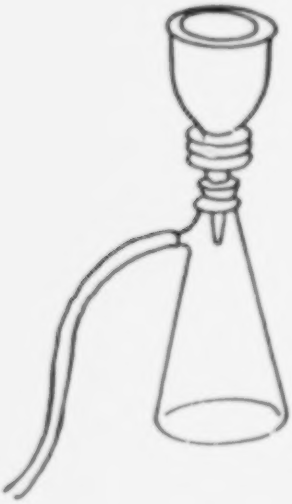
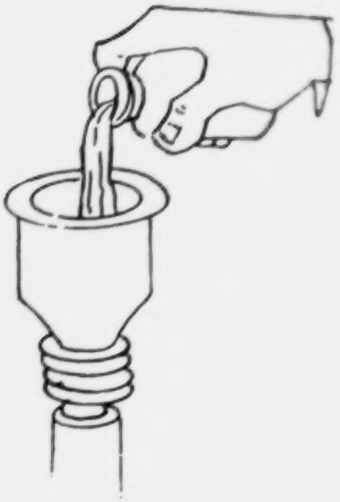
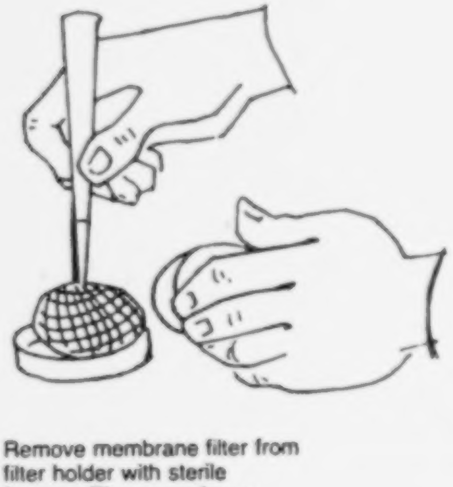


Fig. III



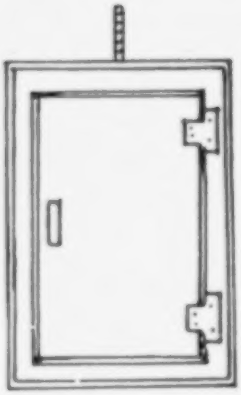
3. Pour or pipet sample aliquot into funnel. Avoid spattering. After suction is applied rinse four times with sterile buffered distilled water.

Fig. IV



4. Remove membrane filter from filter holder with sterile forceps. Place membrane on pad. Cover with petri top.

Fig. V



5. Incubate in inverted position for 22 ± 2 hours.
6. Count coliform appearing colonies on membrane.

tendency for inexperienced persons to make errors on the high side in MF counts. At least five apparent coliform colonies should be transferred to lauryl tryptose broth tubes for verification as coliform organisms.

7. *PROCEDURE FOR FILTRATION OF CHLORINATED SAMPLES USING ENRICHMENT TECHNIQUE*

   a. Place a sterile absorbent pad in the upper half of a sterile petri dish and pipet 1.8 to 2.0 m*L* sterile lauryl tryptose broth. Carefully remove any surplus liquid.

   b. *ASEPTICALLY*[14] place the membrane filter through which the sample has been passed on the pad.

   c. Incubate the filter, without inverting the dish, for 1½ to 2 hours at 35°C in an atmosphere of 90 percent humidity (damp paper towels added to a plastic container with a snap-on lid can be used to produce the humidity).

   d. The enrichment culture is then removed from the incubator. A fresh sterile absorbent pad is placed in the bottom half of the petri dish and saturated with 1.8 to 2.0 m*L* M-Endo Broth.

   e. The membrane filter is transferred to the new pad. The used pad of lauryl tryptose may be discarded.

   f. Invert the dish and incubate for 20 to 22 hours at 35 ± 0.5°C.

   g. Count colonies as in previous method.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 403.

7.3H Why are drinking waters not tested for specific pathogens (such as typhoid and dysentery)?

7.3I To perform coliform tests, how would you decide how many samples to test?

7.3J Why should sodium thiosulfate be added to coliform sample bottles?

7.3K Steam autoclaves sterilize (kill all organisms) at a pressure of ____ psi and temperature of ____ °C during a ____ minute time period (at sea level).

7.3L Estimate the Most Probable Number (MPN) of coliform group bacteria for a raw water sample from the following test results:

m*L* of sample	1	0.1	0.01	0.001
Dilutions	0	−1	−2	−3
Readings (+ tubes)	5	5	3	1

7.3M How is the number of coliforms estimated by the membrane filter method?

7.3N What are the incubation conditions for chlorinated samples when using the membrane filter method?

End of Lesson 4 of 5 Lessons on LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. LABORATORY PROCEDURES

(Lesson 4 of 5 Lessons)

Write the answers to these questions in your notebook. The question numbering continues from Lesson 3.

15. What is the purpose of the coliform group bacteria test?
16. How would you determine the number of dilutions for an MPN test?
17. What factors can cause errors when counting colonies on membrane filters?
18. How can questionable colonies on membrane filters be verified as coliform colonies?

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[14] *Aseptic (a-SEP-tick). Free from the living germs of disease, fermentation, or putrefaction. Sterile.*

Chapter 7. LABORATORY PROCEDURES

(Lesson 5 of 5 Lessons)

5. Hardness

A. Discussion

Hardness is caused principally by the calcium and magnesium ions commonly present in water. Hardness may also be caused by iron, manganese, aluminum, strontium, and zinc if present in significant amounts. Because only calcium and magnesium are present in significant concentrations in most waters, hardness can be defined as the total concentration of calcium and magnesium ions expressed as the calcium carbonate ($CaCO_3$) equivalent.

There are two types or classifications of water hardness: carbonate and non-carbonate. Carbonate hardness is due to calcium/magnesium bicarbonate or carbonate. Hardness that is due to calcium/magnesium sulfate, chloride, or nitrate is termed non-carbonate.

Hard water can cause incrustations (scale) when the water evaporates, or when heated in household hot water heaters and piping. Hardness-producing substances in water also combine with soap to form insoluble precipitates. The common method of minimizing these and other problems due to hardness is water supply softening. This procedure is discussed in Chapter 14, "Softening," in Volume II, of *WATER TREATMENT PLANT OPERATION*.

B. What is Tested

	Common Range mg/L as $CaCO_3$
Surface Water	30 to 500*
Well Water	80 to 500*

*Levels of hardness depend on local conditions.

C. Apparatus

Buret (25 mL)
Buret support
Graduated cylinder (100 mL)

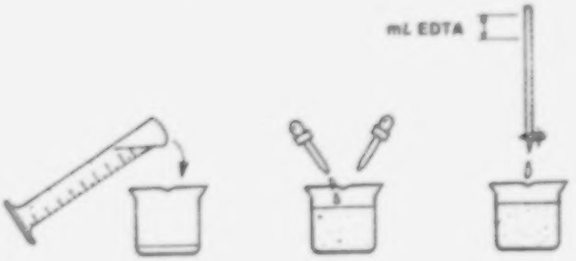
Beaker (250 mL)
Magnetic stirrer
Magnetic stir-bar
Flask, Erlenmeyer (500 mL)
Funnel
Hot plate
Flask, volumetric (1000 mL)

D. Reagents

NOTE: Standardized solutions are available already prepared from laboratory chemical supply companies.

1. Buffer solution.
2. Standard EDTA or CDTA titrant. EDTA is disodium ethylene-diaminetetraacetate dihydrate, also called (ethylenedinitrilo)-tetraacetic acid disodium salt. CDTA is disodium-CTDA (1,2 cyclohexanediaminetetraacetic acid).
3. Indicator solution.

OUTLINE OF PROCEDURE


mL EDTA
1 Add 50 mL of sample to clean beaker
2 Add 2 mL of buffer and 2 drops of indicator
3 Titrate with EDTA to blue end point

E. Procedure

1. Take a clean beaker and add 50 mL of sample.
2. Add 2 mL of buffer solution.
3. Add 2 drops indicator solution.
4. Titrate with standard EDTA solution until the last reddish tinge disappears from the solution. The solution is pure blue when the end point is reached.
5. Calculate total hardness.

F. Example

Results from water hardness testing of a well water sample were as follows:

Sample size = 50 mL

mL of EDTA titrant used, A = 10.5 mL

G. Calculation

$$\text{Hardness, mg/}L\text{ as }CaCO_3 = \frac{A \times 1{,}000}{mL\text{ of sample}}$$

$$= \frac{(10.5\ mL) \times 1{,}000}{50\ mL\text{ of sample}}$$

$$= 210\ mg/L$$

H. Precautions

1. Some metal ions interfere with this procedure by causing fading or indistinct end points. In these cases, an inhibitor reagent should be used. You may titrate with either standard CDTA solution or EDTA solution.
2. The titration should be completed within five minutes to minimize $CaCO_3$ precipitation.
3. A sample volume should be selected that requires less than 15 mL of EDTA titrant to be used.

(Jar Test)

4. For titrations of samples containing low hardness concentrations (less than 150 mg/L as $CaCO_3$) a larger sample volume should be used.

I. Reference

See page 209, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 403.

7.3O What are the principal hardness-causing ions in water?

7.3P What problems are caused by hardness in water?

6. Jar Test

A. Discussion

Jar tests are tests designed to show the effectiveness of chemical treatment in a water treatment facility. Many of the chemicals we add to water can be evaluated on a small laboratory scale by the use of a jar test. The most important of these chemicals are those used for coagulation such as alum and polymers. Using the jar test, the operator can approximate the correct coagulant dosage for plant use when varying amounts of turbidity, color, or other factors indicate raw water quality changes. The jar test is also a very useful tool in evaluating new coagulants or polymers being considered for use on a plant scale.

B. What is Tested

Raw water, for optimum coagulant dose, which varies depending on coagulant(s) used and water quality.

C. Apparatus

1. A stirring machine with six paddles capable of variable speeds from 0 to 100 revolutions per minute (rpm).
2. An illuminator located underneath the stirring mechanism (optional).
3. Beakers (1000 mL).
4. Pipets (10 mL).
5. Flask, volumetric (1000 mL).
6. Balance, analytical.

D. Reagents

1. Stock Coagulant Solution

   a. Dry alum, $Al_2(SO_4)_3 \cdot 14.3\ H_2O$.[15] Dissolve 10.0 g dry alum (17 percent) in 600 mL distilled water contained in a 1000 mL volumetric flask. Fill to mark. This solution contains 10,000 mg/L or 10 mg/mL.

   b. Liquid alum, $Al_2(SO_4)_3 \cdot 49.6\ H_2O$.[15] The operator should verify the strength of the alum with a hydrometer. Liquid alum is usually shipped as 8.0 to 8.5 percent Al_2O_3 and contains about 5.36 pounds of dry aluminum sulfate (17 percent dry) per gallon (specific gravity 1.325). This converts to 624,336 mg/L. Therefore, add 15.6 mL liquid alum to a 1000 mL volumetric flask and fill to mark. This solution contains 10,000 mg/L or 10 mg/mL.

   c. Table 7.5 indicates the strengths of stock solutions for various dosages.

TABLE 7.5 DRY CHEMICAL CONCENTRATIONS USED FOR JAR TESTING[a]

Approx. Dosage Required, mg/L[b]	Grams/Liter to Prepare[c]	1 mL Added to 1 Liter Sample Equals	Stock Solution Conc., mg/L (%)
1-10 mg/L	1 gm/L	1 mg/L	1,000 mg/L (0.1%)
10-50 mg/L	10 gm/L	10 mg/L	10,000 mg/L (1.0%)
50-500 mg/L	100 gm/L	100 mg/L	100,000 mg/L (10.0%)

[a] From *JAR TEST* by E. E. Arasmith, Linn-Benton Community College, Albany, Oregon.

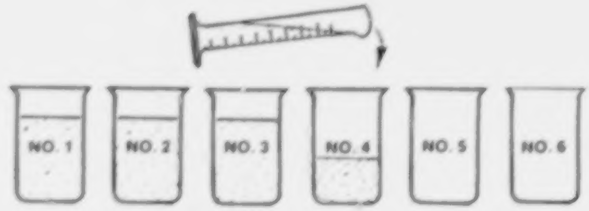
[b] Use this column which indicates the approximate dosage required by raw water to determine the trial dosages to be used in the jar test.

[c] This column indicates the grams of dry chemical that should be used when preparing the stock solution. The stock solution consists of the chemical plus enough water to make a one-liter solution.

E. Procedure

1. Collect two gallons (8 liters) sample of the water to be tested.
2. Immediately measure six 1000-mL quantities and place into each of six 1000-mL beakers.
3. Place all six beakers on stirring apparatus.
4. With a measuring pipet, add increasing dosages of coagulant solution to the beakers as rapidly as possible. Select a series of dosages so that the first beaker will represent an under-dose and the last an over-dose.
5. With stirring paddles lowered into the beakers, start stirring apparatus and operate it for one minute at a speed of 80 rpm.[16]
6. Reduce the stirring speed for the next 30 minutes to 20 rpm.[16]

OUTLINE OF PROCEDURE



1. Add 1000 mL to each of 6 beakers.

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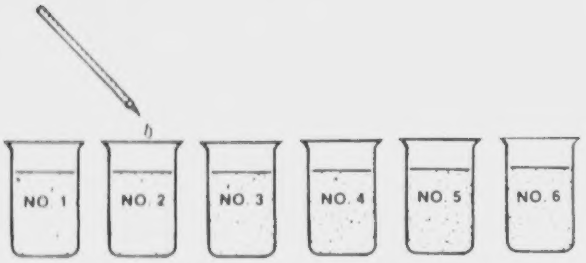
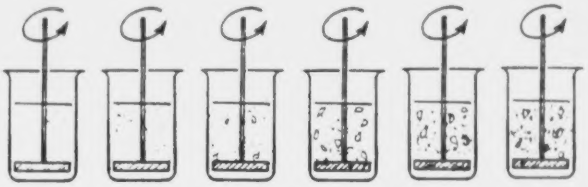
[15] *Values of 14.3 H_2O and 49.6 H_2O were obtained from ALUMINUM SULFATE published by Stauffer Chemicals. Actual values for commercial alum purchased by your water treatment plant may vary slightly.*

[16] *Use stirring speeds and times which are similar to actual conditions in your water treatment plant.*



2. Add increasing dosages of coagulant.



3. Stir for appropriate time period.
Evaluate floc quality.

7. Observe and evaluate each beaker as to that specific dosage's floc quality. Record results.

8. Stop the stirring apparatus and allow samples in beakers to settle for 30 minutes.[16] Observe the floc settling characteristics. A hazy sample indicates poor coagulation. Properly coagulated water contains floc particles that are well-formed and dense, with the liquid between the particles clear. Describe results as poor, fair, good, or excellent.

F. Precautions

Without going to extreme measures, it is very difficult to duplicate in the jar test exactly what is happening on a plant scale. The jar test, therefore, should be used as an indication of what is to be expected on a larger scale in a water treatment plant.

There are a number of tests that can be performed to improve the jar test and the interpretation of the results. These tests include:

1. Alkalinity (before and after),
2. pH (before and after),
3. Turbidity of *SUPERNATANT*[17] (before and after), and
4. Filtered turbidity of supernatant.

See Figure 7.18 for a helpful jar test data sheet.

After estimating the optimum coagulant dosage, run another jar test with the optimum coagulant dosage constant, but vary the pH. These results will give you the optimum pH.

Alkalinity must be monitored very carefully before and after the jar test. Alkalinity must always be *AT LEAST* half of the coagulant dose. For example, if the optimum coagulant dose is 50 mg/*L*, the total alkalinity must be at least 25 mg/*L*. If the natural alkalinity is less than 25 mg/*L*, adjust the total alkalinity up to 25 mg/*L* by adding lime. For additional information on how to calculate the amount of lime needed to increase the alkalinity, see page 174, Section 5.243, "Arithmetic for Solids-Contact Clarification," and page 175, *EXAMPLE 6*, in *WATER TREATMENT PLANT OPERATION*, Volume I.

G. Example

A sample of river water was collected for jar test analysis to determine the "optimum" alum dosage for effective coagulation.

The following series of alum dosage was added:

Beaker No.	m*L* alum solution added	Alum added, mg/*L*
1	1.0	10
2	1.2	12
3	1.4	14
4	1.6	16
5	1.8	18
6	2.0	20

H. Interpretation of Results

Results of the above jar testing were recorded as follows:

Beaker No.	Alum Dose, mg/*L*	Floc Quality
1	10	poor
2	12	fair
3	14	good
4	16	excellent
5	18	excellent
6	20	good

The above results seem to indicate that a dose of 16 or 18 mg/*L* would be optimum. The operator should, however, verify this result with visual observation of what is actually happening in the flocculation basin.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 403.

7.3Q What is the purpose of the jar test?

7.3R What stirring speeds are used during the jar tests for optimum alum dosage?

---

[17] *Supernatant (sue-per-NAY-tent). Liquid removed from settled sludge or floc. Supernatant commonly refers to the liquid between the sludge or floc on the bottom and the water surface of a basin or container (jar).*

JAR TEST DATA SHEET

ANALYST:

DATE:

COAGULANT AID:

pH ADJUST:

SOURCE:

TIME:

COAGULANT:

		TEMP	TURB	pH	ALKA					DESCRIPTION OF FLOC IN JARS								HARDNESS	
JAR NUMBER	SAMPLE SIZE	START / FINISH	START / FINISH	START / FINISH	START / FINISH	FILTERED TURBIDITY	COAG DOSE	COAG-AID DOSE	ADJUSTED pH	1ST APPEAR	5 MIN	10 MIN	15 MIN	20 MIN	25 MIN	30 MIN	45 MIN	START / FINISH	COMMENTS
1																			
2																			
3																			
4																			
5																			
6																			

CODE: VS VERY SMALL; S SMALL; M MEDIUM
D DENSE; VD VERY DENSE; SP SPARCE
L LARGE; VL VERY LARGE

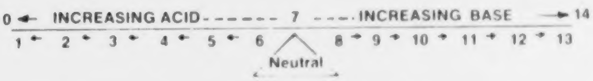
Fig. 7.18 Typical jar test data sheet

7. pH

A. Discussion

The pH of a water indicates the intensity of its acidic or basic intensity. The pH scale runs from 0 to 14. Water having a pH of 7 is at the midpoint of the scale and is considered neutral. Such a water is neither acidic nor basic. A pH of greater than 7 indicates basic water. The stronger the basic intensity, the greater the pH. The opposite is true of the acidity. The stronger the intensity of the acidity, the lower will be the pH.

pH SCALE



Mathematically, pH is the logarithm of the reciprocal of the hydrogen ion activity, or the negative logarithm of the hydrogen ion activity.

$$\mathrm{pH} = \log \frac{1}{(\mathrm{H}^+)} = -\log (\mathrm{H}^+)$$

For example, if a water has a pH of 1, then the hydrogen ion activity $(\mathrm{H}^+) = 10^{-1} = 0.1$. If the pH is 7, then $(\mathrm{H}^+) = 10^{-7} = 0.0000001$. A change in the pH of one unit is caused by changing the hydrogen ion level by a factor of 10 (ten times).

In a solution, both hydrogen ions (H^+) and the hydroxyl ions (OH^-) are always present. At a pH of 7, the activity of both hydrogen and hydroxyl ions equals 10^{-7} *MOLES*[18] per liter. When the pH is less than 7, the activity of hydrogen ions is greater than the hydroxyl ions.

pH plays an important role in the water treatment processes such as disinfection, coagulation, softening, and corrosion control. The pH test also indicates changes in raw and finished water quality.

B. What is Tested

	Common Range
Surface water	6.5 to 8.5
Finished water	7.5 to 9.0
Well water	6.5 to 8.0

C. Apparatus

1. pH meter
2. Glass electrode
3. Reference electrode
4. Magnetic stirrer
5. Magnetic stir-bar

D. Reagents

1. Buffer tablets for various pH value solutions (available from laboratory chemical supply houses).
2. Distilled water.

E. Procedure

1. Due to the difference between the various makes and models of pH meters commercially available, specific instructions cannot be provided for the correct operation of all instruments. In each case, follow the manufacturer's instructions for preparing the electrodes and operating the instrument.
2. *STANDARDIZE THE INSTRUMENT AGAINST A BUFFER SOLUTION WITH A pH CLOSE TO THAT OF THE SAMPLE.*
3. Rinse electrodes thoroughly with distilled water after removal from buffer solution.
4. Place electrodes in sample and measure pH.
5. Remove electrodes from sample, rinse thoroughly with distilled water.
6. Immerse electrode ends in beaker of pH 7 buffer storage solution.
7. Turn meter to "standby" (or off).

F. Precautions

1. To avoid faulty instrument calibration, prepare fresh buffer solutions as needed, and at least one per week (from commercially available buffer tablets).
2. pH meter, buffer solution, and samples should all be near the same temperature because temperature variations will give somewhat erroneous results.
3. Watch for erratic results arising from electrodes, faulty connections, or fouling of electrodes with oily precipitated matter.
4. The temperature compensator on the pH meter adjusts the meter for changes in electrode response with temperature. However, the pH of water also changes with temperature and the pH meter cannot compensate for this change.
5. We recommend standardizing the pH meter using a pH buffer solution close to the pH of the sample. However, if you use another buffer solution with a different pH to determine the calibration of the pH meter for a range of pH values and the pH meter does not give the pH of the second buffer, follow manufacturer's directions to adjust the pH meter. This procedure is called adjusting the "slope" of the pH meter.

G. Interpretation of Results

The pH of water has a very important influence on the effectiveness of chlorine disinfection. Chlorination is a chemical reaction in which chlorine is an oxidizing agent. Chlorine is a more effective oxidant at lower pH values. Simply stated, a chlorine residual of 0.2 mg/*L* at a pH of 7 is just as effective a 1 mg/*L* at a pH of 10. Therefore, five times as much chlorine is required to do the same disinfecting job at pH 10 as it does at pH 7.

The finished water of some treatment facilities is adjusted with lime or caustic soda to the slightly basic pH for the purpose of minimizing corrosion in the distribution system.

H. Reference

See page 429, *STANDARD METHODS*, 16th Edition.

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[18] *Mole. The molecular weight of a substance, usually expressed in grams.*

(Temperature)

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 403.

7.3S What does the pH of a water indicate?

7.3T What precautions should be exercised when using a pH meter?

8. Temperature

A. Discussion

Temperature is one of the most frequently taken tests in the water industry. Accurate water temperature readings are important not only for historical purposes but also because of its influence on chemical reaction rates, biological growth, dissolved gas concentrations, and water stability with respect to calcium carbonate, in addition to its acceptability by consumers for drinking.

B. What is Tested

	Common Range, °C
Raw and Treated Surface Water	5 to 25
Well Water	10 to 20

C. Apparatus

1. One NBS (National Bureau of Standards) thermometer for calibration of the other thermometers.
2. One Fahrenheit mercury filled, 1° subdivided thermometer.
3. One Celsius (formerly called Centigrade) mercury-filled, 1° subdivided thermometer.
4. One metal case to fit each thermometer.

NOTE: There are three types of thermometers and two scales.

SCALES

1. Fahrenheit, marked °F.
2. Celsius, marked °C (formerly Centigrade).

THERMOMETER STYLES

1. Total immersion. This type of thermometer must be totally immersed when read. Readings with this type of thermometer will change most rapidly when removed from the liquid to be recorded.
2. Partial immersion. This type thermometer will have a solid line (water-level indicator) around the stem below the point where the scale starts.
3. Dial. This type has a dial that can be easily read while the thermometer is still immersed. Dial thermometer readings should be checked (calibrated) against the NBS thermometer. Some dial thermometers can be recalibrated (adjusted) to read at a set temperature against the NBS thermometer.

D. Reagents

None required.

E. Procedure

1. Collect as large a volume of sample as is practical. The temperature will have less chance to change in a large volume than in a small container.
2. Immerse the thermometer to the proper depth. Do not touch the bottom or sides of the sample container with the thermometer.
3. Record temperature to the nearest fraction of a degree which can be estimated from the thermometer available.
4. When measuring the temperature of well water samples, allow the water to continuously overflow a small container (a polystyrene coffee cup is ideal). Place the thermometer in the cup. After there has been no change in the temperature reading for one minute, record the temperature. The temperature of water samples collected from a distribution system mainly depend on the soil temperature at the depth of the water main.

F. Precautions

To avoid breaking or damaging a glass thermometer, store it in a shielded metal case. Check your thermometer accuracy against the NBS certified thermometer by measuring the temperature of a sample with both thermometers simultaneously. Some of the poorer quality thermometers are substantially inaccurate (off as much as 6°F or 3°C).

G. Example

To measure the temperature of treated water, a sample was obtained in a gallon bottle, the thermometer immediately immersed, and a temperature of 15°C recorded after the reading became constant.

H. Calculation

Normally we measure and record temperatures using a thermometer with the proper scale. We could, however, measure a temperature in °C and convert to °F. The following formulas are used to convert temperatures from one scale to the other.

1. If we measure in °F and want °C,

$$°C = \frac{5}{9}(°F - 32)$$

2. If we measure in °C and want °F,

$$°F = \frac{9}{5}(°C) + 32$$

3. Sample Calculation

The measured treated water temperature was 15°C. What is the temperature in °F?

$$\begin{aligned} °F &= 9/5\ (°C) + 32 \\ &= 9/5\ (15°C) + 32 \\ &= 27 + 32 \\ &= 59°F \end{aligned}$$

I. Reference

See page 126, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 403.

7.3U Why are temperature readings important?

7.3V Why should the thermometer remain immersed in the liquid while being read?

7.3W Why should thermometers be calibrated against an accurate NBS certified thermometer?

9. Turbidity

A. Discussion

The term turbidity is simply an expression of the physical cloudiness of water. Turbidity is caused by the presence of suspended matter such as silt, finely-divided organic and inorganic matter, and microscopic organisms such as algae.

The accepted method used to measure turbidity is called the nephelometric method. The nephelometric turbidimeter or nephelometer (Figure 7.19) is designed to measure particle-reflected light at an angle of 90 degrees to the source beam. The greater the intensity of scattered light, the higher the turbidity.

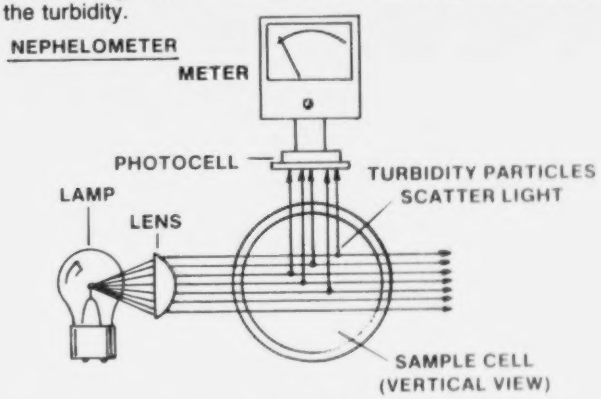
NEPHELOMETER
METER
PHOTOCELL
TURBIDITY PARTICLES SCATTER LIGHT
LAMP
LENS
SAMPLE CELL (VERTICAL VIEW)

Fig. 7.19 Nephelometer
(Permission of Hach Company)

The turbidity unit (NTU) is an empirical quantity which is based on the amount of light that is scattered by particles of a polymer reference standard called formazin which produces particles that scatter light in a reproducible manner. Formazin, the primary turbidity standard, is an aqueous suspension of an insoluble polymer formed by the condensation reaction between hydrazine sulfate and hexamethlenetetramine.

Secondary turbidity standards are suspensions of various materials formulated to match the primary formazin solutions. These secondary standards are generally used because of their convenience and the instability of dilute formazin primary standard solutions. Examples of these secondary standards include "standards" that are supplied by the turbidimeter manufacturer with the instrument. Periodic checks of these secondary standards against the primary formazin standard are a must and will provide assurance of measurement accuracy.

The turbidity measurement is one of the most important tests the plant operator performs. The Safe Drinking Water Act stipulates specific monitoring requirements for turbidity. Turbidity of treated surface water must be measured continuously or determined daily and the results reported to the appropriate authority. Turbidity testing is the most critical tool in recognizing changes in raw water quality, detecting problems in coagulation and sedimentation, and troubleshooting filtration problems.

The maximum contaminant level (MCL) for turbidity is one TU with five TU allowed under certain circumstances. Water treatment plant operators should strive to produce a finished water with a turbidity of 0.1 TU or less.

B. What is Tested

	Common Range, NTU
Untreated Surface Water	1 to 300
Filtered Water	0.03 to 0.50
Well Water	0.05 to 1.0+

C. Apparatus

1. Turbidimeter: To minimize differences in turbidity measurements, rigorous specifications for turbidimeters are necessary. The turbidimeter should have the following important characteristics:
   a. The turbidimeter should consist of a nephelometer with a light source illuminating the sample, and one or more photoelectric detectors to indicate the intensity of scattered light at a 90° angle with a "readout" device.
   b. The light source should be an intense tungsten filament lamp.
   c. The total distance traveled by the light through the sample should be less than about 5 centimeters.
   d. The instrument should have several measurement ranges. The instrument should be able to measure from 0 to 100 turbidity units, with sufficient sensitivity (on the lowest scale) to detect differences of 0.02 or less in filtered waters having turbidities of less than one unit.
2. Sample tubes. These are usually provided with the instrument.

D. Reagents

1. Turbidity-free water: Pass distilled water through a membrane filter having a pore size no greater than 0.2 microns (available from laboratory supply houses). Discard the first 200 m*L* collected. If filtration does not reduce turbidity of the distilled water, use unfiltered distilled water.
2. Stock Formazine turbidity suspension:[19]
   a. Solution I — Dissolve 1.000 g hydrazine sulfate in distilled water and dilute to 100 m/*L* in a volumetric flask.

---

[19] *Stock secondary standard turbidity suspensions that require no preparation are available from commercial suppliers and approved for use.*

(Turbidity)

b. Solution II — Dissolve 10.00 g hexamethylenetetramine in distilled water and dilute to 100 m*L* in a volumetric flask.

c. In a 100 m*L* volumetric flask, add (using 5 m*L* volumetric pipets) 5.0 m*L* Solution I and 5.0 m*L* of Solution II. Mix and allow to stand 24 hours at 25°C. Then dilute to the mark and mix. The turbidity of this suspension is considered 400 NTU exactly.

d. Prepare solutions and suspensions monthly.

3. Standard turbidity suspensions: Dilute 10.00 m*L* stock turbidity suspension to 100 m*L* with turbidity-free water. Prepare weekly. The turbidity of this suspension is defined as 40 NTU.

4. Dilute turbidity standards: Dilute portions of the standard turbidity suspension with turbidity-free water as required. Prepare weekly.

E. Procedure

1. Turbidimeter calibration: the manufacturer's operating instructions should be followed. Measure your standard solutions on the turbidimeter covering the range of interest. If the instrument is already calibrated in standard *TURBIDITY UNITS,*[20] this procedure will check the accuracy of the calibration scales. At least one standard should be run in each instrument range to be used. Some instruments permit adjustments of sensitivity so that scale values will correspond to turbidities. Reliance on an instrument manufacturer's scattering standards for calibrating the instrument is not an acceptable practice unless they are in acceptably close agreement with prepared standards. If a pre-calibrated scale is not supplied, then calibration curves should be prepared for each usable range of the instrument.

2. Turbidities less than 40 units: Shake the sample to thoroughly disperse the suspended solids. Wait until air bubbles disappear, then pour the sample into the turbidimeter tube. Read the turbidity directly from the instrument scale or from the appropriate calibration curve.

3. Turbidities exceeding 40 units: Dilute the sample with one or more volumes of turbidity-free water until the turbidity falls below 40 units. The turbidity of the original sample is then computed from the turbidity of the diluted sample and the dilution factor.

F. Example

A reservoir sample was collected and the turbidity was found to be greater than 40 units when first checked. 30 m*L* of this sample was then diluted with 60 m*L* of turbidity-free water. This diluted sample showed a turbidity of 25 units.

NTU found in diluted sample, A	= 25 NTU
m*L* of dilution water used, B	= 60 m*L*
m*L* of sample volume taken for dilution, C	= 30 m*L*

G. Calculation

$$\text{Nephelometric Turbidity Units (NTU)} = \frac{(A) \times (B + C)}{C}$$

$$= \frac{(25\ \text{NTU}) \times (60\ mL + 30\ mL)}{30\ mL}$$

$$= 75\ \text{NTU}$$

H. Interpretation of Results

Report turbidity results as follows:

Turbidity Reading	Record to Nearest
0.0 to 1.0	0.05
1 to 10	0.1
10 to 40	1
40 to 100	5
100 to 1000	10
>1000	100

Notes and Precautions

1. Sample tubes must be kept scrupulously clean, both inside and out. Discard them when they become scratched or etched. Never handle them where the light strikes them.

2. Fill the tubes with samples and standards that have been agitated thoroughly, and allow sufficient time for bubbles to escape.

3. Turbidity should be measured in a sample as soon as possible to obtain accurate results. The turbidity of a sample can change after the sample is collected. Shaking the sample will not recreate the original turbidity.

J. Reference

See page 131, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 404.

7.3X What are the causes of turbidity in water?

7.3Y How is turbidity measured?

7.4 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A.135, "Laboratory Procedures." Check all of the arithmetic in this section using an electronic pocket calculator. You should be able to get the same answers.

7.5 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 4, "Water Chemistry," Chapter 5, "Microbiology," and Chapter 21, "Laboratory Examinations of Water."

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[20] *Turbidity Units (TU) (ter-BID-it-tee). Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.*

2. *TEXAS MANUAL*, Chapter 6, "Water Chemistry," and Chapter 12, "Laboratory Examinations."

7.6 WATER LABORATORY TESTS IN *WATER TREATMENT PLANT OPERATION*, Volume II

Laboratory procedures for the following tests are provided in *WATER TREATMENT PLANT OPERATION*, Volume II, Chapter 21, "Advanced Laboratory Procedures."

1. Algae Counts
2. Calcium
3. Chloride
4. Color
5. Dissolved Oxygen
6. Fluoride
7. Iron
8. Manganese
9. Marble Test
10. Nitrate
11. Phosphate
12. Sulfate
13. Threshold Odor
14. Total Dissolved Solids
15. THMs

End of Lesson 5 of 5 Lessons on LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. LABORATORY PROCEDURES

(Lesson 5 of 5 Lessons)

HOW
WHAT
WHY

Write the answers to these questions in your notebook before continuing with the Objective Test on page 404. The question numbering continues from Lesson 4.

19. What precautions should be considered when performing the hardness determination on a water sample?
20. How could you estimate the most effective dose of alum, or a polymer in a water treatment process?
21. What precautions should be exercised when taking temperature measurements?
22. Why should turbidity be measured in a sample as soon as possible?

SUGGESTED ANSWERS

Chapter 7. LABORATORY PROCEDURES

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 346.

7.0A Laboratory control tests are important because they provide the necessary information to control the treatment processes and insure a safe and good-tasting drinking water.

7.0B The prefix milli means 1/1000 (0.001) of the unit following.

7.0C The proper name of the chemical compound $CaCO_3$ is calcium carbonate.

Answers to questions on page 355.

7.1A Descriptions of laboratory glassware and their use or purpose.

Item	Description	Use or Purpose
1. Beakers	Short, wide cylinders in sizes from 1 mL to 4000 mL	Mixing chemicals
2. Graduated cylinders	Long, narrow cylinders in sizes from 5 mL to 4000 mL	Measuring volumes
3. Pipets	Small diameter graduated tubes, with a pointed tip, in sizes from 1.0 mL to 100 mL	Delivering accurate volumes
4. Burets	Long tubes with graduated walls and a stopcock in sizes from 10 mL to 1000 mL	Delivering and measuring accurate volumes used in "titrations"

7.1B Never heat graduated cylinders in an open flame because they may break.

7.1C A meniscus is the curve of the surface of a liquid in a small tube.

Answers to questions on page 357.

7.1D A "standard solution" is a solution in which the exact concentration of a chemical or compound in a solution is known.

7.1E Laboratory notebooks and worksheets help record data in an orderly manner.

7.1F Four sources or causes of poor quality of analytical data are:

1. Sloppy laboratory technique,
2. Deteriorated reagents and standards,
3. Poorly operating instruments, and
4. Calculation mistakes.

Answers to questions on page 363.

7.1G Six laboratory hazards are:

1. Hazardous materials,
2. Explosions,
3. Cuts and bruises,
4. Electric shock,
5. Fire, and
6. Burns (heat and chemical).

7.1H *NEVER* work all alone in the laboratory. Someone should always be available to help in case you should have an accident which blinds you, leaves you unconscious, or starts a fire you can't handle. If necessary have someone check on you regularly to be sure you are OK.

7.1I Dispose of small amounts of corrosive acids by pouring the acid down corrosion-resistant sinks and sewers using large quantities of water to dilute and flush the acid.

7.1J True. You may add acid to water, but never the reverse.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 366.

7.2A The greatest errors in laboratory tests are frequently caused by (1) improper sampling, (2) poor sample preservation, and (3) lack of enough mixing during testing.

7.2B A representative sample must be collected or the test results will have little significant meaning. The test results will not reflect actual water conditions. To efficiently operate a water treatment plant, the operator must rely on test results to indicate what is happening in the treatment process.

7.2C Sampling points in a distribution system should be selected in order to trace the course from the finished water source, whether it be a well or plant, through the transmission mains, and then through the major and minor arteries of the system.

Answers to questions on page 370.

7.2D The two general types of samples collected by water treatment personnel are (1) grab samples, and (2) composite samples.

7.2E Water quality indicators that are usually measured with a grab sample include (1) dissolved gases, (2) coliform bacteria, (3) residual chlorine, (4) temperature, and (5) pH.

7.2F Depth samples are collected by the use of a Kemmerer Sampler or similar device. The sampling device and container are lowered to the desired depth, then opened, filled, closed, and returned to the surface.

7.2G Samples should not be collected from taps surrounded by excessive foliage (leaves, flowers) or from taps that are dirty, corroded, or are leaking.

7.2H When collecting a sample, record the sample location, date and time of collection, name of collector, and any other pertinent information.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 373.

7.3A Chemicals used in water treatment that will cause changes in alkalinity include alum, chlorine, and lime.

7.3B Alkalinity is used in calculating chemical dosages needed in coagulation and water softening. Alkalinity must also be known to calculate corrosivity and to estimate carbonate hardness of a water.

Answers to questions on page 376.

7.3C The benefits of chlorinating water include:

1. Disinfection;
2. Improved quality of water due to chlorine reacting with iron, manganese, protein substances, sulfide, and many taste- and odor-producing compounds;
3. Control of microorganisms that might interfere with coagulation and flocculation;
4. Keeps filter media free of slime growths; and
5. Helps bleach out undesirable color.

7.3D A potential adverse effect from chlorination is the possibility of the formation of carcinogenic chlororganic compounds such as chloroform and other THMs.

Answers to questions on page 379.

7.3E Conditions that can cause variations in the chlorine demand of water include (1) the amount of chlorine applied, (2) time of contact, (3) pH, (4) temperature, (5) organics, and (6) reducing agents.

7.3F The operator uses the chlorine demand test to determine the best chlorine dosage to achieve specific chlorination objectives.

7.3G Chlorine Demand, mg/*L* = Chlorine Added, mg/*L* − Free Residual Chlorine, mg/*L*
= 2.0 mg/*L* − 0.4 mg/*L*
= 1.6 mg/*L*

ANSWERS TO QUESTIONS IN LESSON 4

Answers to questions on page 392.

7.3H Drinking waters are not tested for specific pathogens because the tests are very time-consuming and require special techniques and equipment.

7.3I The number of samples required for coliform tests is generally based on the population served by the water system.

7.3J Sodium thiosulfate should be added to sample bottles for coliform tests to neutralize any residual chlorine in the sample. If the residual chlorine is not neutralized, it would continue to be toxic to the coliform organisms remaining in the sample and give false (negative) results.

7.3K Steam autoclaves sterilize (kill all organisms) at a pressure of *15* psi and temperature of *121°C* during a *15* minute time period (at sea level).

7.3L

mL of sample	0.1	0.01	0.001
Dilutions	−1	−2	−3
Readings (+ tubes)	5	3	1

MPN = 11,000/100 mL

7.3M The number of coliforms is determined by counting the number of coliform appearing colonies grown on the membrane filter.

7.3N Incubate the filter, without inserting the dish for 1½ to 2 hours at 35°C in an atmosphere of 90 percent humidity. Transfer the membrane filter to a new pad enriched with M-Endo Broth. Invert the dish and incubate for 20 to 22 hours at 35 ± 0.5°C.

ANSWERS TO QUESTIONS IN LESSON 5

Answers to questions on page 394.

7.3O The principal hardness-causing ions in water are calcium and magnesium.

7.3P Problems caused by hardness in water include (1) incrustations when water evaporates or scale when heated and (2) formation of precipitates when combined with soap.

Answers to questions on page 395.

7.3Q The jar test is used to (1) determine the correct coagulant dosage and (2) evaluate new coagulants or polymers.

7.3R Speeds used during the jar test are as follows:

1. 80 rpm for the first minute,
2. 20 rpm for the next 30 minutes, and
3. Stop stirring for the next 60 minutes.

These speeds should be adjusted if necessary to be similar to actual conditions in the water treatment plant.

Answers to questions on page 398.

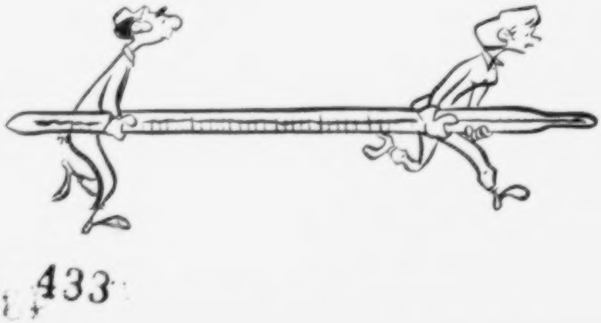
7.3S The pH of a water indicates the intensity of its basic or acid strength.

7.3T Precautions to be exercised when using a pH meter include:

1. Prepare fresh buffer solution weekly for calibration purposes;
2. Have pH meter, samples, and buffer solutions all near the same temperature;
3. Watch for erratic results arising from faulty operation of pH meter or fouling of electrodes with interfering matter;
4. The pH of water changes with temperature; and
5. If testing waters with a range of pH values, the "slope" of the pH meter may require adjusting.

Answers to questions on page 399.

7.3U Temperature readings are important because temperature influences chemical reaction rates, biological growth, dissolved gas concentrations, and water stability with respect to calcium carbonate. Also consumers are sensitive to the temperature of the water they drink.



7.3V The thermometer should remain immersed in the liquid while being read for accurate results. When removed from the liquid, the reading will change.

7.3W All thermometers should be calibrated against an accurate National Bureau of Standards thermometer because some (cheaper) thermometers are substantially inaccurate (off as much as 6°F or 3°C).

Answers to questions on page 400.

7.3X Turbidity in water can be caused by the presence of suspended matter such as silt, finely divided organic and inorganic matter, and microscopic organisms such as algae.

7.3Y Turbidity is measured by the nephelometric method.

OBJECTIVE TEST

CHAPTER 7. LABORATORY PROCEDURES

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True — False

1. Composite samples should be used to measure the temperature of water.
   1. True
   2. False
2. When preparing a composite sample, the individual samples must be vigorously mixed before the portion for the composite is withdrawn and then the entire composite sample should be vigorously mixed.
   1. True
   2. False
3. Always wear safety glasses or goggles whenever any possible danger exists to your eyes.
   1. True
   2. False
4. The treatment plant superintendent is the only person responsible for lab safety.
   1. True
   2. False
5. A rubber bulb should be used to pipet raw water.
   1. True
   2. False
6. Acids can injure you, but not bases (hydroxides).
   1. True
   2. False
7. The pH scale ranges from 1 to 14.
   1. True
   2. False
8. Acid may be added to water but not the reverse.
   1. True
   2. False
9. End point titration may be based on a color change.
   1. True
   2. False
10. A water with a pH of 7 is basic.
    1. True
    2. False
11. Carbonate hardness is the only type of hardness encountered in water supply systems.
    1. True
    2. False
12. All bottles containing chemicals must be clearly labeled.
    1. True
    2. False
13. The jar test is used to measure the corrosivity of water.
    1. True
    2. False
14. The Safe Drinking Water Act stipulates specific monitoring requirements for turbidity.
    1. True
    2. False
15. Jar tests duplicate exactly what is happening in a plant.
    1. True
    2. False

Multiple Choice

16. Large errors in laboratory tests may be caused by
    1. Improper sampling.
    2. Lack of mixing during compositing.
    3. Large samples.
    4. Poor preservation.
    5. Poor quality product water.
17. Poor data quality results from
    1. Calculation mistakes.
    2. Deteriorated reagents.
    3. Polluted raw waters.
    4. Poorly operating instruments.
    5. Sloppy laboratory techniques.
18. Physical properties of water are described by
    1. Alkalinity.
    2. Chlorine.
    3. Color.
    4. Odor.
    5. Turbidity.

19. The most accurate way to deliver accurate volumes of a sample is to use
    1. Beakers.
    2. Cylinders (graduated).
    3. Flasks.
    4. Graduates.
    5. Pipets.
20. The chemical symbol C stands for
    1. Calcium.
    2. Carbon.
    3. Chlorine.
    4. Copper.
    5. Cyanide.
21. Water may be used to extinguish fires caused by
    1. Electrical equipment.
    2. Grease.
    3. Paint.
    4. Sodium.
    5. Textiles.
22. Explosive or flammable materials an operator may encounter include
    1. Acetone.
    2. Hydrochloric acid.
    3. Ethyl ether.
    4. Gasoline.
    5. Sodium hydroxide.
23. A grab sample may be preferred over a composite sample when
    1. An overall description of the water for a 24-hour period is needed.
    2. The water quality indicators of interest will deteriorate with time.
    3. The water quality indicators of interest will not deteriorate with time.
    4. The water to be sampled does not flow on a continuous basis.
    5. The water's characteristics are relatively constant.
24. Water samples from a distribution system should be collected from a
    1. Drinking fountain.
    2. Fire hydrant.
    3. Leaky faucet.
    4. Sampling station.
    5. Tap surrounded by foliage.
25. The membrane filter method for the coliform test
    1. Diffuses nutrients through the membrane to grow bacteria into colonies.
    2. Estimates MPN by the production of gas in inverted tubes or vials.
    3. Ideally should produce between 50 and 200 coliform colonies.
    4. Produces the same results as the multiple fermentation tube method.
    5. Uses a cellulose ester filter.
26. Chlorine is used in water treatment to react with
    1. Coagulants.
    2. Iron.
    3. Floc.
    4. Pathogens.
    5. Taste- and odor-producing compounds.
27. Alkalinity in a natural water sample may include
    1. Bicarbonate alone.
    2. Bicarbonate and carbonate.
    3. Carbonate alone.
    4. Carbonate and hydroxide.
    5. Hydroxide alone.
28. Manual water sampling equipment includes
    1. Dippers.
    2. Cross-section samplers.
    3. Glass jars.
    4. Hand-operated pumps.
    5. Weighted bottles.
29. Jar tests may be used to determine the optimum dosage of
    1. Alum.
    2. Chlorine.
    3. Fluorine.
    4. Magnesium.
    5. Polymer.
30. In addition to calcium and magnesium, hardness in water may be caused by
    1. Aluminum.
    2. Iron.
    3. Manganese.
    4. Potassium.
    5. Sodium.

Data to answer questions 31 and 32.

Results from MPN tests during one week were as follows:

Day	S	M	T	W	TH	F	S
MPN/100 m*L*	8	11	4	15	6	12	7

31. The mean MPN/100 m*L* from the data is
    1. 4
    2. 6
    3. 7
    4. 8
    5. 9
32. The median MPN/100 m*L* from the data is
    1. 4
    2. 6
    3. 7
    4. 8
    5. 9

End of Objective Test

CHAPTER 8

SETTING WATER RATES FOR SMALL WATER UTILITIES

by

James D. Beard

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OBJECTIVES

Chapter 8. SETTING WATER RATES FOR SMALL WATER UTILITIES

Following completion of Chapter 8 you should be able to:

1. Determine revenue needs for a small water utility,
2. Itemize various system expenses,
3. Relate costs to level of service,
4. Distribute costs to customers,
5. Keep accurate records of costs and sources of revenues, and
6. Develop water rates for a small water utility.

GLOSSARY

Chapter 8. SETTING WATER RATES FOR SMALL WATER UTILITIES

BASE-EXTRA-CAPACITY METHOD BASE-EXTRA-CAPACITY METHOD

A cost allocation method used by water utilities to determine water rates for various water user groups. This method considers base costs (O & M expenses and capital costs), extra capacity costs (additional costs for maximum day and maximum hour demands), customer costs (meter maintenance and reading, billing, collection, accounting) and fire protection costs.

BOND BOND

(1) A written promise to pay a specified sum of money (called the face value) at a fixed time in the future (called the date of maturity). A bond also carries interest at a fixed rate, payable periodically. The difference between a note and a bond is that a bond usually runs for a longer period of time and requires greater formality. Utility agencies use bonds as a means of obtaining large amounts of money for capital improvements. (2) A warranty by an underwriting organization, such as an insurance company, guaranteeing honesty, performance, or payment by a contractor.

COMMODITY-DEMAND METHOD COMMODITY-DEMAND METHOD

A cost allocation method used by water utilities to determine water rates for the various water user groups. This method considers the commodity costs (water, chemicals, power, amount of water use), demand costs (treatment, storage, distribution), customer costs (meter maintenance and reading, billing, collection, accounting) and fire protection costs.

DEBT SERVICE DEBT SERVICE

The amount of money required annually to pay the (1) interest on outstanding debts; or (2) funds due on a maturing bonded debt or the redemption of bonds.

DEPRECIATION DEPRECIATION

The gradual loss in service value of a facility or piece of equipment due to all the factors causing the ultimate retirement of the facility or equipment. This loss can be caused by sudden physical damage, wearing out due to age, obsolescence, inadequacy or availability of a newer, more efficient facility or equipment. The value cannot be restored by maintenance.

EQUITY EQUITY

The value of an investment in a facility.

FIXED COSTS FIXED COSTS

Costs that a utility must cover or pay even if there is no demand for water or no water to sell to customers. Also see VARIABLE COSTS.

OVERHEAD OVERHEAD

Indirect costs necessary for a water utility to function properly. These costs are not related to the actual production and delivery of water to consumers, but include the costs of rent, lights, office supplies, management and administration.

RATE OF RETURN RATE OF RETURN

A value which indicates the return of funds received on the basis of the total equity capital used to finance physical facilities. Similar to the interest rate on savings accounts or loans.

VARIABLE COSTS VARIABLE COSTS

Costs that a utility must cover or pay that are associated with the production and delivery of water. The costs vary or fluctuate on the basis of the volume of water treated and delivered to customers (water production). Also see FIXED COSTS.

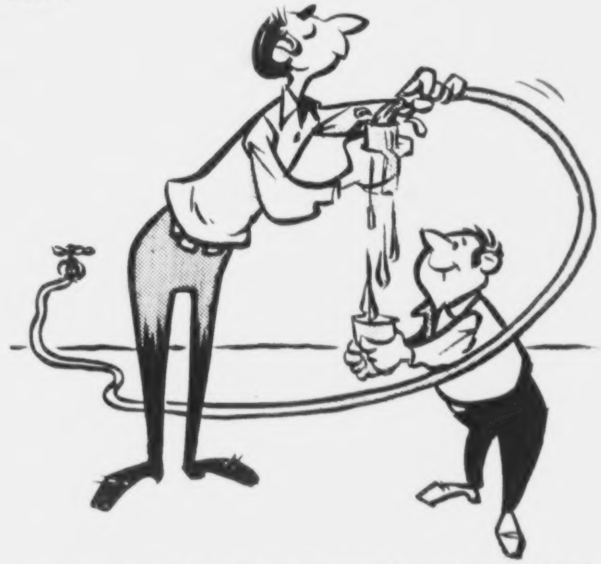
CHAPTER 8. SETTING WATER RATES FOR SMALL WATER UTILITIES

8.0 DEVELOPING WATER RATES

8.00 General Rate Setting Philosophy

The goal established by the American Water Works Association (AWWA) for setting water rates is that each utility develop a rate setting methodology that fairly allocates costs to various classes of water users, and then recovers these costs through rates which will sustain the enterprise and not unduly discriminate against any particular class of users. To put this goal in simpler terms—rates should be "cost based" and "nondiscriminatory."

As water utility managers, we must develop rate setting practices and procedures which fairly allocate costs to the classes of users that benefit most from our services. Again, the burden of water costs should not be unfairly thrust upon any individual class of customers whether they be small or large, new or old, domestic or commercial/industrial water users.



A second goal in rate setting is stability of rates. Careful analysis of past projected costs will help you avoid frequent, unexpected rate increases. No matter how fair and equitable the rate structure is, sudden large increases upset consumers and raise questions about the competence of the utility manager. A rate structure that is fair to all customers reflects well on your integrity and a rate structure that is stable and predictable over a period of years reflects well on your professional ability.

In this chapter we will describe rate setting practices and procedures which can be readily used by small water utilities. We will use the AWWA definition of a small utility—one having fewer than 5,000 customers (active service connections).

It would be helpful if a simple formula or model could be used to establish water rates—but this is seldom the case. Each water utility is unique and this yields special sets of circumstances which need to be fully considered in setting fair water rates.

Since a simple formula isn't available, cost-of-service or rate studies are usually conducted to establish fair and equitable rates. The results of these studies are highly dependent on the accuracy and reliability of the utility's information and recordkeeping systems. For larger utilities more comprehensive rate studies may be needed but for smaller utilities it is generally advisable to keep rate studies simple. However, even in the small utility, full or partial rate studies may be required when the utility has a substantial industrial base or other special water sale categories or customers.

The procedures and practices described in this chapter should be used as guidelines to establish rates and charges. Each water utility is unique and will have its own special considerations to deal with. By using these procedures the small utility should be able to develop a cost-based, fair, and reasonable set of rates and charges which accurately reflect the cost-of-service for each class of consumer.

8.01 General Plan of Attack

The first step in setting water rates is to develop a general plan of attack. That is to say, we need to outline the specific steps we'll take to reach our goal. Fortunately, many of the resources that we will need are readily available to use in the form of budgets, budget reports showing conformance to the spending plan, and customer-related records. Hopefully, the customer records will include such essential information as water usage and customer-related operation and maintenance expenses.

Armed with a good working knowledge of our past financial and operating history, we can begin to develop a schedule of water rates and charges by using the following procedures:

1. Determine total annual revenue requirements;
2. Allocate revenue requirements to cost components;
3. Distribute component costs to customer classes; and
4. Design rates that will recover these costs from each class of customer.

The following sections will describe each of these procedures in enough detail that you can apply them to your own water utility. Figure 8.1 outlines the plan of attack or procedures developed in this chapter for an operator to determine water rates for a small utility agency. As you begin this procedure, keep in mind one basic difference between budget planning for a utility and budgeting your own personal expenses. You probably begin with a fixed annual income and try to adjust your expenses to fit within that amount. In budgeting for a utility, you will begin by figuring out all present and anticipated expenses and then set fair and equitable rates that will produce the amount of annual income needed.

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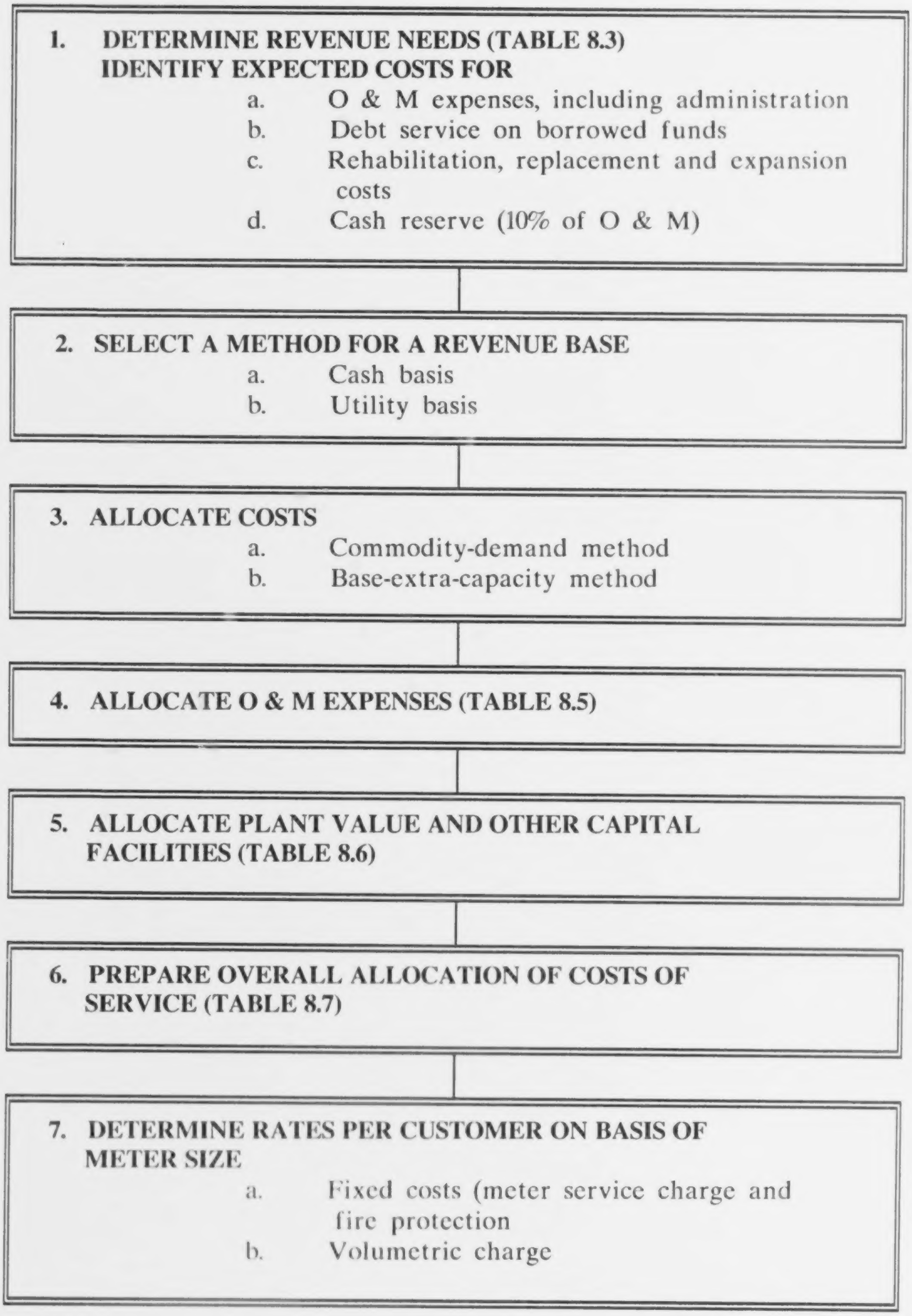
[1] *American Water Works Association (AWWA). A professional organization for all persons working in the water utility field. This organization develops and recommends goals, procedures and standards for water utility agencies to help them improve their performance and effectiveness.*

PLAN OF ATTACK



1. **DETERMINE REVENUE NEEDS (TABLE 8.3) IDENTIFY EXPECTED COSTS FOR**
   - a. O & M expenses, including administration
   - b. Debt service on borrowed funds
   - c. Rehabilitation, replacement and expansion costs
   - d. Cash reserve (10% of O & M)
2. **SELECT A METHOD FOR A REVENUE BASE**
   - a. Cash basis
   - b. Utility basis
3. **ALLOCATE COSTS**
   - a. Commodity-demand method
   - b. Base-extra-capacity method
4. **ALLOCATE O & M EXPENSES (TABLE 8.5)**
5. **ALLOCATE PLANT VALUE AND OTHER CAPITAL FACILITIES (TABLE 8.6)**
6. **PREPARE OVERALL ALLOCATION OF COSTS OF SERVICE (TABLE 8.7)**
7. **DETERMINE RATES PER CUSTOMER ON BASIS OF METER SIZE**
   - a. Fixed costs (meter service charge and fire protection
   - b. Volumetric charge

Fig. 8.1 Procedure to determine water rates

8.02 Let's Develop a Hypothetical Water District

To better illustrate the application of the rate setting procedures in this chapter, a hypothetical water district will be used as a model water utility.

Assume that the XYZ Water District has 4,000 customers (services) and serves a predominantly residential community with a population of approximately 11,200 people. It has two large industrial users and several small commercial users. Water-related statistics for this water district are given in Table 8.1.

XYZ WATER DISTRICT
POPULATION 11,200

TABLE 8.1 SERVICE AREA STATISTICS

SERVICE AREA SIZE = 8 sq miles
SOURCES OF SUPPLY
Surface Water = 25%
Groundwater = 75%
CUSTOMERS (SERVICES) = 4,000
POPULATION
(4,000 Services)(2.8 Persons/Household) = 11,200
AVERAGE DAILY CONSUMPTION = 1.71 MGD
WATER USE (From Meter Records)
RESIDENTIAL (11,200)(125 GPD) = 1.40 MGD
INDUSTRIAL: 1 @ 100,000 GPD
1 @ 75,000 GPD
175,000 GPD = 0.18 MGD
COMMERCIAL = 0.05 MGD
MISCELLANEOUS = 0.08 MGD
Average Daily Use = 1.71 MGD

MAXIMUM DAILY CONSUMPTION
(1.40 MGD)(1.8 Residential Peak Factor) + 0.31 MGD = 2.83 MGD
SYSTEM DESIGN FLOW CAPACITY
(1.71 MGD)(1.25 Capacity Factor) = 2.13 MGD

Given the average daily consumption of 1.71 MGD, the annual water use for this community would be about 625 million gallons or 1,915 acre-feet. However, treatment plant, storage, and distribution facilities must be sized to deliver maximum day demand with some margin of safety (25 percent is used in this example).

8.1 REVENUE REQUIREMENTS

8.10 Determining Revenue Needs

Developing a statement of revenue requirements which accurately reflects the cash needs of our utility is the first step in our plan of attack for setting water rates. If we have developed a good budget and spending plan, this should merely be an extension of existing budgeting and accounting practices.

Our objective is to determine the cash needs and timing of expenditures (cash flow) for the utility. Examples of typical revenue needs are:

- O & M expenses
- Debt service on borrowed funds
- Rehabilitation and replacement costs
- Administrative expenses related to the operation of our system

To avoid cash flow shortages during the rate period, we need to be sure to project our revenue needs far enough into the future and allow for emergencies and contingencies (unplanned events). Sometimes it is best to project several years into the future even though the rate period is typically only one year.

We also need to allow for unexpected decreases in water demand, inflation, and system growth since these factors do play a significant role in setting stable water rates. A good historical data base from which to project future needs will greatly assist in setting long-term rates.

Revenue requirements may be broadly divided into two major categories—Operating Expenses and Capital Costs. A description of these costs is given in Table 8.2.

TABLE 8.2 MAJOR REVENUE REQUIREMENTS

OPERATING EXPENSES (O & M)
- Costs of operating the plant, reservoir, groundwater, and distribution systems
- Costs of maintaining facilities and equipment
- Administration

CAPITAL COSTS
- Annual costs associated with plant construction investment
- Debt service expenses (principal and interest on bonds or other loans)
- Facilities replacement costs
- Facilities extension (expansion) costs
- Facilities improvement costs, including new facilities

8.11 Forecasting Expenditures

As previously mentioned, it is necessary to forecast expenses carefully in establishing a stable system of rates and charges. *A stable system is one in which rates are* *adequate to cover all anticipated expenses and still maintain a positive cash position at the end of the rate period.* This avoids "bumping rates" up in the middle of the rate period, and allows the utility to build a modest cash reserve which can be called upon in times of serious financial need. A good rule-of-thumb for a small water system is to establish a general fund reserve which is a minimum of 10 percent of one year's O & M expenses. Special reserve funds may also need to be established for capital program needs.

In forecasting future expenditures the following items should be considered:

- Unexpected decreases in water demand
- System growth rate
- Anticipated inflation
- Long-range capital improvement program needs
- Long-range financing requirements

INFLATION
RATES

A major concern when projecting future revenue needs is the sensitivity of water demand projections and the ability of revenues from water sales to meet projected target values. A drop in planned water sales by only ten percent in a below normal water year could have a significant impact on projected revenue from water sales for a small water utility.

To minimize the financial impact of variable water sales, a water utility might consider establishing a dry-year contingency reserve whereby a small surcharge is assessed each year (on a monthly or bimonthly billing basis) and these funds are set aside for use during dry years or when there is an unexpected drop in demand. Since dry periods typically occur only in one or two years out of every ten in most regions, building up a reserve is a good method for making up reduced revenue during periods when water is not available due to drought or the demand drops due to a shift in economic conditions.

Another method of guarding against an unexpected drop in revenue during dry years is to make sure that the *FIXED COSTS*[2] are always recovered by water rates. Since a high percentage of the revenue requirement can be assigned to fixed cost items, a rate structure can be established that is not too dependent on the commodity or volume charge component. If a fluctuating or unstable demand is a concern in a cost analysis, consider shifting some of the *VARIABLE COSTS*[3] or volumetric cost burden to the customer service charge component. Always try to design water rates in a manner that will recover base (fixed) costs.

The growth rate of your community may have a significant impact on water demand, capital facility, and staffing needs. If your community is growing rapidly you will need a long-range as well as a short-range capital improvement program designed to meet system demands as they occur over time. A short-range program is generally forecast for one to five years into the future. Whereas a long-range program may estimate system demands and facility needs for 25 years or more into the future. Obviously, short-range planning is much better focused than long-range programs. We need to review our long-range planning program periodically and revise these plans as appropriate.

Just as important as long-range capital facility planning is the need to finance these programs. Generally, water rates alone are not an adequate method of financing most major capital improvements. Other financing methods such as bonds and development-related charges and fees are generally required to cover growth related capital expenditures. These will be discussed in later sections.

Inflation is another important consideration in setting stable water rates. There are two general components of inflation which will affect rates and charges—Consumer Price Index or CPI, and Construction Cost Index or CCI. The CPI is established by the Federal Government and is published for most areas of the United States. The CPI should be applied to general O & M expense items such as materials and supplies as well as labor. The CCI published by "Engineering News Record" magazine is generally used for estimating construction-related capital improvement costs. It is advisable to use both of these indices since inflation rates may impact differently on these two major sectors of the economy.

8.12 Development of Cost Centers

In order to develop a complete statement of our revenue needs, we need to look more closely at our plant and facility expenses. As you read through this section, look at Table 8.3 to see how each expense item is listed in an overall statement of projected revenue requirements.

Let's assume that the surface water source of supply for our water district is contracted for from another water agency and this accounts for about 25 percent of our needs, or 480 acre-feet per year. Further, let's assume that we take this water from a service connection in a "joint-use aqueduct," and that raw water storage is accomplished in a common upstream reservoir. Raw water transmission and storage costs are included in the $150 per acre-foot water charge. In order to treat this water, we own and operate a small 1 MGD water treatment plant. So, costs associated with the surface water source of supply and treatment would include the following:

O & M EXPENSES	
- Source of supply ($150/ac-ft)(480 ac-ft)	$ 72,000
- Chemicals ($5/ac-ft)(480 ac-ft)	2,400
- Power ($12/ac-ft)(480 ac-ft)	5,670
- Labor	100,000
DEBT SERVICE EXPENSES	
- Water treatment plant costs	120,000
REPAIR, REPLACEMENT, EXTENSIONS AND IMPROVEMENT EXPENSES	
- Surface water system	35,000

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[2] *Fixed Costs. Costs that a utility must cover or pay even if there is no demand for water or no water to sell to customers.*

[3] *Variable Costs. Costs that a utility must cover or pay that are associated with the production and delivery of water. The costs vary or fluctuate on the basis of the volume of water treated and delivered to customers (water production).*

TABLE 8.3 PROJECTED REVENUE REQUIREMENTS FOR XYZ WATER DISTRICT

EXPENSE ITEM	UNIT PRICE ($/AF)	EXPENSE REVENUE REQUIREMENTS ($)
O & M EXPENSES		
• Source of Supply		
- Surface water (water cost,transmission and storage)	150	72,000
- Groundwater (recharge and replenishment)	50	71,750
• Power		
- Surface water treatment plant	12	5,760
- Groundwater pumping	25	38,875
- Distribution system pumping	10	5,000
• Water Treatment		
- Surface water treatment chemicals	5	2,400
- Groundwater treatment chemicals	3	4,305
- Labor		100,000
• Transmission and Distribution		
- Storage reservoirs		5,000
- Mains		30,000
- Meters		20,000
- Valves		5,000
- Service lines		10,000
- Fire hydrants		3,000
• Administration and general		
- Meter reading		25,000
- Billing and collection		40,000
- General administration		50,000
- Fringe benefits		35,000
DEBT SERVICE EXPENSES[a]		
- Water treatment plant		120,000
- Wells		16,000
- Transmission and distribution system		60,000
- Other capital (service lines, meters, hydrants, etc.)		24,000
MAJOR REPAIR, REPLACEMENT, EXTENSION AND IMPROVEMENT EXPENSES[b]		
- Surface water treatment plant		35,000
- Well sites		7,000
- Transmission and distribution system		28,000
Total Revenue Requirement		$810,090

[a] Debt service is equal annual payments spread over 25 years (to retire bonds/loans).

[b] Repair and replacements calculated at 2 percent of plant's value.

The groundwater source of supply for our water district provides about 75 percent of our needs, or about 1,435 acre-feet per year. Production facilities which are owned and operated by the district to meet this need include five 350-GPM wells. Costs associated with groundwater production include:

O & M EXPENSES

- Source of supply (recharge and replenishment) ($50/ac-ft)(1,435 ac-ft)	$ 71,750
- Chemicals ($3/ac-ft)(1,435 ac-ft)	4,305
- Power ($25/ac-ft)(1,435 ac-ft)	35,875

DEBT SERVICE EXPENSES

- Wells	16,000

REPAIR, REPLACEMENT, EXTENSION AND IMPROVEMENT EXPENSES

- Well sites	7,000

Joint surface water/groundwater transmission, storage, and distribution facilities include five treated-water storage reservoirs totaling 8.5 MG of operational storage, 50 miles of transmission mains, valve structures, a booster pumping station, and a public fire protection system. Costs of the distribution system include:

O & M EXPENSES

- Storage reservoirs	$ 5,000
- Distribution	
- Mains	30,000
- Meters	20,000
- Valves	5,000
- Service lines	10,000
- Fire hydrants	3,000
- Power for pumping	5,000

DEBT SERVICE EXPENSES

- Transmission and distribution	60,000
- Service lines, meters and hydrants	24,000

REPAIR, REPLACEMENT, EXTENSION AND IMPROVEMENT EXPENSES

- Transmission and distribution	28,000

Costs of administration and general expenses items include:

ADMINISTRATION AND GENERAL EXPENSES

- Meter reading	$ 25,000
- Billing and collection	40,000
- Administration	50,000
- Fringe benefits	35,000

These administration and general expenses are usually included as a separate cost category under O & M expenses.

8.13 Two Different Methods of Establishing Revenue Base

There are two basic accounting methods for establishing the revenue base: (1) the cash basis, and (2) the utility basis. Using the "cash basis," the utility must raise enough money to cover all cash needs including *DEBT SERVICE*.[4] The cash basis is generally used by publicly owned utilities and is, therefore, the focus of this chapter. It is essentially an extension of the cash-oriented budgeting and accounting system used by many governmental agencies.

Revenue base requirements (as illustrated in Table 8.3) include:

- O & M expenses
- Administration and general expenses
- Debt service expenses
- Capital expense
- Cash reserves

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[4] *Debt Service. The amount of money required annually to pay the (1) interest on outstanding debts; or (2) funds due on a maturing bonded debt or the redemption of bonds.*

Operation and maintenance expenses are usually based on actual expenditures and are adjusted to reflect conditions expected to occur during the rate period. Historical spending patterns are normally used as a starting point for developing cost estimates. System operation and maintenance expense items include:

- Purchased water
- Water treatment
- Salaries and fringe benefits (for O & M)
- Power costs
- Water transmission and distribution
- Outside services (contracts)
- Equipment rental
- Materials and supplies

Administration and general expenses include:

- Salaries and fringe benefits (administrators, secretarial, janitorial)
- Building rental
- Meter reading
- Billing and collection

These administration and general expenses are usually listed under operation and maintenance expenses.

Debt service expenses on bonds or other loans include:

- Principal and interest

Capital expense items include:

- Replacements (equipment)
- Main extensions and improvements
- Major rehabilitation of facilities
- Cash reserves

Routine repair and replacement of capital facilities of a minor nature are generally financed from current revenues. Most major capital projects are financed by *BONDS*[5] or developer-related fees and charges due to the need to match, as near as possible, the repayment period over the useful life of the facilities. This helps to avoid putting the burden of cost for these facilities on current users when facilities are designed to meet current as well as future system demands.

The "utility basis" for determining revenue requirements is used primarily by investor-owned utilities. However, some publicly owned utilities may also use this method to establish rates for customers outside the utility's service area. The major difference in this accounting method is that it entitles the utility owner to a reasonable rate of return (profit) on *EQUITY*[6] in the system. To accommodate this additional cost item, capital costs are additionally broken down into two other components: (1) depreciation expenses, and (2) return-on-rate base.

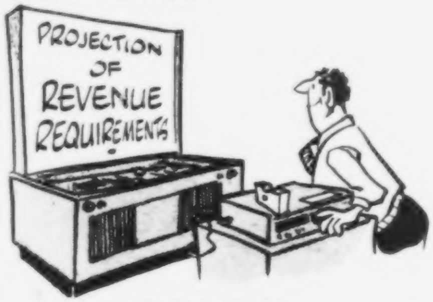
Depreciation expense is related to the gradual loss in service value of facilities and equipment over time due to age (wear and tear, obsolescence). Depreciation expense essentially provides for recovery of the capital investment over the useful life of the facility and equipment. The rate-of-return component is designed to pay the cost of debt service and to provide a fair rate of return for total equity capital used to finance physical facilities.

The utility method requires development of a "rate base" (value of assets on which the utility is entitled to earn a return). The rate base is usually based on the value of the utility's plant and property actually used to serve the utility's customers.

In contrast to the cash basis accounting method, capital improvement costs in the utility basis accounting method are recovered through depreciation (wear and tear) and rate of return (debt service), and no provision is made for reserves. Since these cost items tend to be offsetting, the revenue requirement could actually be less under the utility basis for capital items. This possibility should be thoroughly investigated if you are considering using the utility basis for a public or municipal utility.

The total revenue requirement for investor-owned utilities includes:

- O & M expenses
- Administration and general expenses
- Federal and State income taxes
- Other taxes (i.e., property)
- Depreciation expense
- Return-on-rate base



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 425.

8.0A What are the goals of a fair water rate setting program?

8.0B What types of costs are considered operation and maintenance expenses?

8.1A List the types of capital costs that must be covered by revenue.

8.1B What are the two general components of inflation which will affect setting of rates and charges?

8.1C List the costs associated with a water distribution system.

8.2 COST ALLOCATION METHODS

8.20 Relate Costs to Level of Service

If all water users made similar demands on the water system then this section would not be necessary. We could simply divide the total revenue requirements of the utility by the average water use and thus allocate costs evenly across the board. This is usually not the case, however, so costs need to be allocated to customers on the basis of their particular service requirements.

Water service to customers has two distinct components: (1) average demand, and (2) peak flow demand. These demands differ between customer classes and require the utility to provide different levels of service (plant and facilities) to meet these demands. As an illustration, a class of customers with a very high peak rate of use (flow) as compared with the average use may require larger capacity pumps, larger sized mains, and additional reservoir storage capacity. The water rate for this class of customer should reflect their proportionate share of user's *peak*, as well as the average usage. A customer with a high peak rate of use is sometimes referred to as having a "poor load factor."

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[5] *Bond. A written promise to pay a specified sum of money (called the face value) at a fixed time in the future (called the date of maturity). A bond also carries interest at a fixed rate, payable periodically. The difference between a note and a bond is that a bond usually runs for a longer period of time and requires greater formality. Utility agencies use bonds as a means of obtaining large amounts of money for capital improvements.*

[6] *Equity. The value of an investment in a facility.*

In the following sections we will review two popular cost allocation methods used to assign costs to appropriate levels of service. The two methods are called:

1. Commodity-demand method, and
2. Base-extra-capacity method.

Cost allocation methods which require the use of significant amounts of personal judgment should be avoided.

8.21 Commodity-Demand Method

The commodity-demand cost allocation method is most appropriate for use by small utilities since it is less complicated to administer, but it should be noted that it may not be as accurate as the base-extra-capacity method in some instances.

In order to distribute costs of service to user groups by the commodity-demand cost allocation method, we must first identify utility costs related to the following service categories:

- Commodity (water) charges
- Demand (peak flow)
- Customer service costs
- Public fire protection

Commodity costs tend to vary as a function of *average* water use. These costs include:

- Purchased water
- Chemicals
- Power costs
- Other costs directly related to the amounts of water use

Demand costs are associated with providing facilities to meet *peak rates* of use and include:

- Transmission and distribution system pumping capacities
- Treatment plant flow capacity
- Transmission and distribution mains
- Storage facilities sized to meet peak demands
- Source of supply costs such as "peaking wells" (wells used only during periods of high demand)

These cost components may be further broken down to assign specific demands to maximum day and maximum hour users.

Customer service costs are primarily those related to providing service to customers, regardless of the amount of water used. Customer costs include:

- Meter and service line maintenance
- Meter reading and billing
- Customer accounting
- Collection costs

Public fire protection costs are primarily demand-related due to the nature of this use. These costs can be allocated based on cost-of-service studies that seem to fit your specific needs or you can estimate these costs based on standard curves such as the one given in AWWA Manual M-1.[7] A summary of the AWWA allocation method is given in Table 8.4. These costs can be distributed to all public fire protection system users. To use Table 8.4 you must know the number of customers served. For example, if the number of customers served is 1000, then Table 8.4 indicates that 28 percent of the total revenue can be allocated to fire protection costs.

TABLE 8.4 ALLOCATION OF FIRE PROTECTION COSTS[a]

NUMBER OF CUSTOMERS	PERCENTAGE OF TOTAL REVENUE
500	32.0
1000	28.0
2000	24.0
3000	21.5
4000	20.0
5000	18.5

[a] *Adapted from AWWA WATER RATES Manual No. M-1.*

8.22 Base-Extra-Capacity Method

The base-extra-capacity method of cost allocation has four major cost components:

1. Base costs
2. Extra capacity costs
3. Customer costs
4. Direct fire protection costs

Base costs tend to vary as a function of total water quantity used and include O & M and capital costs associated with service to customers under average load conditions (excludes peak demand elements). Base costs include:

- O & M expenses of supply, treatment, pumping and distribution facilities
- Capital costs related to plant investment to serve average system flow

Extra capacity costs are those required to meet demands in excess of average use. These include O & M and capital costs for system capacity over and above the average flow rate. Extra capacity costs may be further subdivided into additional costs to meet:

1. Max-day extra demand costs
2. Max-hour extra demand costs
3. Other extra demand-related costs

Customer costs and direct fire protection costs are allo-

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[7] *WATER RATES (M-1), Order No. 30001. Available from Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Price to members, $13.00; nonmembers, $16.00.*

TABLE 8.5 ALLOCATION OF O & M EXPENSES

EXPENSE ITEM	TOTAL[a] $	COMMODITY $	DEMAND $	CUSTOMER $	DIRECT FIRE PROTECTION,$
Source of Supply:					
- Surface Water	72,000[b]	50,400	21,600	0	0
- Groundwater	71,750[b]	50,225	21,525	0	0
Power:					
- Surface Water T.P.	5,760[b]	4,030	1,730	0	0
- Groundwater Pumping	35,875[b]	25,100	10,775	0	0
- Dist. System Pumping	5,000[b]	3,500	1,500	0	0
Water Treatment:					
- Plant Treat. Chemicals	2,400	2,400	0	0	0
- Well Treat. Chemicals	4,305	4,305	0	0	0
- Labor	100,000[b]	70,000	30,000	0	0
Transmission & Dist:					
- Storage Reservoirs	5,000	0	5,000	0	0
- Mains	30,000	0	30,000	0	0
- Meters	20,000	0	20	20,000	0
- Valves	10,000	0	5,000	0	0
- Service Connections	10,000	0	0	10,000	0
- Fire Hydrants	3,000	0	0	0	3,000
Admin. & General:					
- Meter Reading	25,000	0	0	25,000	0
- Billing & Collection	40,000	0	0	40,000	0
(Subtotal for percent to last two lines)	435,090	209,960	197,130	95,000	3,000
- General Administration (Labor)	50,000[c]	24,000	14,500	11,000	500
- Fringe Benefits	35,000[c]	16,800	10,100	7,700	350
TOTALS	520,090	250,760	151,780	113,700	3,850

NOTES:
[a] From Table 8.3
[b] Allocation - 70% Commodity
30% Demand
[c] Based on other allocation totals.

cated in the same way as they were in the commodity-demand cost allocation method described in Section 8.21.

To split costs between base and extra capacity we usually use an "allocation factor." For example, assume the maximum daily use exceeds average daily use by a factor of two. This factor can be used to allocate applicable cost components to users responsible for the maximum daily use. In a similar way, a factor based upon actual or estimated flow measurements can be used to allocate maximum hourly and other peaking demands.

When allocating costs for portions of certain facilities required to accommodate peaking demands, be sure to use good judgement in developing allocation factors which are fair to all users and based upon all the facts available to you.

The greatest advantage of this cost allocation method is its ability to establish the minimum cost of service under ideal (average) conditions. By using this minimum cost figure to establish base minimum costs, you will avoid setting rates that could result in selling water below cost.

8.23 Examples of Cost Allocations

In order to illustrate the allocation of costs to various user groups, we will use the commodity-demand method described in Section 8.21 and apply it to our hypothetical water district.

The first step in distributing costs is the allocation of operation and maintenance expenses, as shown in Table 8.5. The figures used in Table 8.5 are those that we projected to be the revenue needs of our water district in Table 8.3.

Cost allocations to the commodity component are primarily expenses which relate to volume of water delivered such as water cost, power and chemical costs, and the bulk of labor for operating and maintaining the water system.

Costs allocated to the demand component represent expenses associated with peak operation of the water system, including a portion of the system operation and maintenance labor.

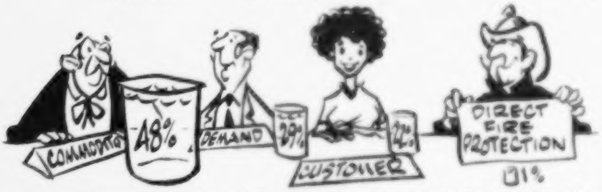
Customer costs are those not related to volume of water or peak flows. In other words, these costs would be incurred regardless of the amount of water used by the customer.

In this illustration we used a split of 70% commodity and 30% demand allocation for some of the expense items.[8] However, in actual applications these allocation percentages should be based on actual water use data or reasonable estimates of who uses how much water. The general administration and fringe benefits expense items were spread to all categories based on the overall weighted average subtotal of all other expenses. This is a generally acceptable method of allocating these costs. In this example the following procedure was used with the information in Table 8.5 to develop the allocation percentages for administration and fringe benefits:

---

[8] *From Table 8.1 the average daily residential consumption was 1.4 MGD and the maximum daily consumption was (1.4 MGD) (1.8) = 2.52 MGD. Therefore the percent commodity demand would be (100%) (1.4 MGD) / (2.52 MGD) = 68%. For ease of calculations use a split of 70% commodity and 30% demand allocation.*

COST COMPONENTS IN TABLE 8.5	SUM OF EXPENSE ITEMS EXCEPT ADMIN & FRINGE	ALLOCATION PERCENTAGE	
- Commodity	$ 209,960	$\frac{(209,906)(100\%)}{435,090}$	= 48%
- Demand	197,130	$\frac{(197,130)(100\%)}{435,090}$	= 29%
- Customer	95,000	$\frac{(95,000)(100\%)}{435,090}$	= 22%
- Direct fire protection	3,000	$\frac{(3,000)(100\%)}{\$\,435,090}$	= 1%
TOTALS	$ 435,090		100%



It should be noted that if you compare cost figures for the commodity-demand method and the base-extra capacity method, you may see major differences in the percentage allocations between individual water systems for "commodity" and "demand" categories. This occurs because the commodity and demand categories are defined by individual system configuration and water users' demands.

The next step is to allocate capital expense items, but before we can do this we need to develop an overall allocation schedule of plant and facility values. This allocation is shown in Table 8.6, and these values are the basis of the long-term debt service expenses shown in Table 8.3. The annual revenue requirements are determined on the basis of the period of debt payment (25 years) and the interest rate (6%). With this information you can use a table found in engineering economic textbooks which will give a factor (0.08) which is multiplied times the "total plant value" to give the "annual revenue requirements." Table 8.6 also includes other capital expense items such as service lines, meters, and hydrants.

Again, the major differences in this schedule are found in the commodity and demand components. Using the commodity-demand method of cost allocation, major plant facilities, including those designed to supply peak-day or peak-hour demands, are assigned to the demand component. In the base- extra-capacity method, these costs would be broken down between base costs and extra-capacity costs according to the demands of the users. While the latter method is more complex, it also provides a more accurate allocation of expenses if system demands vary considerably during the year.

The last step in cost allocation is to combine these costs into a summary table which reflects the overall cost of service. Such an allocation summary for our hypothetical water district is given in Table 8.7, which includes capital-related expenses for debt service and major repair, replacements, extension, and improvement expenses. Note that we used the cost allocation values given in Table 8.4 to offset fire protection costs because these will be paid as a separate cost item. If this amount proves to be too high or too low, then a cost-of-service study or other analysis should be conducted to establish a more appropriate value.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 425.

8.2A To distribute costs using the commodity-demand method, list the utility service cost categories.

8.2B What is a commodity cost?

8.2C What is a demand cost?

8.2D What is a customer cost?

8.3 DISTRIBUTION OF COSTS TO CUSTOMERS

8.30 Establishing Customer Classes

The next step in our planning effort is to establish different classes of water service by customer groups. In setting up customer classes you must be sure to create sufficient classes and broad enough category definitions to cover all user groups. Always keep in mind that the overall intent of establishing customer classes is to group customers into categories of similar *use patterns*. Thus classes should separate users by load demand and peaking characteristics.

TABLE 8.6 ALLOCATION OF PLANT VALUE AND OTHER CAPITAL FACILITIES

CAPITAL ITEM	TOTAL $	COMMODITY $	DEMAND $	CUSTOMER $	DIRECT FIRE PROTECTION, $
Water Treatment Plant	1,500,000	0	1,500,000	0	0
Wells	200,000	0	200,000	0	0
Trans. & Dist. System	750,000	0	750,000	0	0
Other Capital					
- Service Connections	150,000	0	0	150,000	0
- Meters	90,000	0	0	90,000	0
- Hydrants	60,000	0	0	0	60,000
Total "Physical Plant" Value	2,750,000	0	2,450,000	240,000	60,000
Annual Revenue Requirements[a]	220,000	0	196,000	19,200	4,800

---

[a] Based on equal debt payments over 25 years and approximately 6% compound interest factor (0.08). Multiply "Total Physical Plant Value" by 0.08 to obtain "Annual Requirements."

TABLE 8.7 OVERALL ALLOCATION OF COST SERVICE

ITEM	TOTAL $	COMMODITY $	DEMAND $	CUSTOMER $	DIRECT FIRE PROTECTION $
O & M Expenses[a]	520,090	250,750	151,780	113,700	3,850
Capital Expenses					
- Debt Serv.[b]	220,000	0	196,000	19,200	4,800
- Major Repair & Replacement[c]	70,000	0	70,000	0	0
Total Cost of Service	810,090	250,750	417,780	132,900	8,650
Less Fire Protection Revenue[d]	<162,000>	—	<153,350>	—	<8,650>
General Cost of Water Service	648,090	250,760	264,430	132,900	0

NOTES:

[a] From Table 8.5.

[b] Based on Annual Revenue Replacements Given in Table 8.6.

[c] From Table 8.3.

[d] 20% of Revenue Based on Table 8.4. Values on this line subtracted because they will be paid as a separate cost item.

While the process of establishing customer classes will vary depending on a system's unique mix of customers, the following general customer classes are frequently used by many water utilities:

1. Residential
2. Commercial
3. Industrial
4. Agricultural (irrigation)
5. Other (public authority, government, etc.)

Residential customers are typically single-family residences. In some instances, this class includes multiple-family dwelling units. Commercial customers are non-industrial, business, and service-type enterprises. Industrial customers are generally manufacturing and processing enterprises. Agricultural customers may be heavy irrigation users or livestock or poultry feeding operations. The "other" category may be designated for schools, governmental uses, parks and recreation.

8.31 Special Considerations

In distributing costs to customers you will need to give special consideration to such items as:

- Unusual service characteristics
- Demand patterns
- Wholesale vs. retail use
- Interruptible service options
- Inside vs. outside service area

Unusual service characteristics are unique factors which require special consideration for a particular customer or class of users. For example, demand patterns could influence rates for heavy irrigation users or other seasonal users such as canneries. In addition, if a system has both wholesale and retail customers, recognition should be given to the wholesalers during periods when they operate at less than 100 percent capacity. You may want to establish a lower rate as an incentive for customers to contract for interruptible service. This type of service contract allows the utility to cut off service during periods of high system demand or under drought conditions. For customers who reside outside of district boundaries, you may want to set a slightly higher rate to provide a return on capital investment within the system. In some cases, special assessments may be charged to customers at higher elevations in the form of a pressure zone surcharge to cover additional pumping and storage costs. In any event, the intent of distributing costs to different classes of water use is to recognize the differing demands on the water system and thereby set water rates which accurately reflect the actual cost-of-service to each customer class.

8.32 Capital Contributions

Traditionally, bonds have been used to finance major capital improvements to the water system. In recent years, however, there has been increasing pressure to include capital costs which are general in nature when calculating the general water rate. Other capital costs incurred, for such uses as system expansion required by new development, might better be met by new-user capital contributions in the form of connection fees or other related charges.

Connection fees are generally "up-front" fees paid by new users connecting to the system to cover new capital costs incurred to provide service to their property. Or, new users are sometimes required to pay a "buy-in" fee at the time of connection to the system to pay back an appropriate portion of capital already invested in the water system. User-fee-based financing systems are often referred to as "pay-as-you-go" financing. The advantages of this method of assessment are that it avoids payment of interest expense on long-term debt and does not put all of the burden of system expansion on current rate payers.

8.4 RATE DESIGN

8.40 General

The final step in our plan of attack is to design water rates which will recover appropriate costs from each class of customer. In this section we will develop a typical water bill for our hypothetical water district.

Simplified methods of rate design can be used in small utilities when the cost of preparing a comprehensive rate study are prohibitive. However, when a utility, regardless of size, has special circumstances such as a large industrial base, a comprehensive or partial rate study may be in order.

While rates should always be based on cost-of-service, good judgement must also be used in rate setting. Remember that the goal is to develop a rate structure which attains the maximum degree of equity among all customer classes.

Before we proceed we need to touch on a somewhat thorny issue in some parts of the country—metered vs. unmetered customers. It has generally been shown that unmetered customers tend to use more water than an equivalent metered customer. Therefore, providing service tc unmetered customers when the metering option is available is discouraged. In this section we will assume that all customers are metered.

8.41 Information and Data Requirements

In order to set accurate rates that differentiate between customer classes, we need a good historical data base from which information on the various user classes can be taken. General information and data requirements include the following:

1. Revenue requirements for the projected rate period in sufficient detail to permit allocation to cost categories;
2. A bill-frequency analysis of metered water use by customer class and meter size; and
3. A record of the number and size of meters for each customer class.

The basic revenue requirement for our hypothetical water district was developed in Section 8.13, and is illustrated in Table 8.3. A further breakdown and allocation of the revenue requirement is given in Tables 8.5 and 8.7.

A bill-frequency analysis can be prepared manually by summarizing metered water use data for a given period of time, say the last 3 to 5 years. With the assistance of a personal computer this data base can be easily established on a spreadsheet and updated routinely on a monthly basis.

Records of the number and size of meters installed in the system can be manually determined from customer records. Again, the use of a personal computer can greatly reduce the effort required to produce this information in a readily usable format.

By analyzing the above data we can determine if water use patterns differ significantly from the average, and if so, which customer classes are responsible for these deviations. If the makeup of the water system is predominantly residential, you may not find any major deviations. But if significant differences are noted in a given customer's use pattern, then consider establishing a separate rate for this water user. In many cases, a uniform rate for the commodity-demand cost components may prove to be quite satisfactory.

8.42 Rate Components

To establish the overall water rate for our hypothetical water district, we will divide the rate up into four major components:

1. Service charge,
2. Volume charge,
3. Fire protection charge, and
4. Miscellaneous charge.

The service charge is designed to recover customer-related costs such as meter reading expenses. These costs are incurred regardless of the amount of water used, and are distributed over all customer classes. The service charge is based on meter size. However, if revenue from your water sales fluctuates widely, consider shifting more of your costs to the service charge to avoid revenue shortages.

The volume charge should reflect the costs associated with actual water use. In a true commodity-demand system, this charge would be broken down into the two components of commodity and demand volumes. To do this on an ongoing basis, however, demand water meters would be required and these meters are generally not cost-effective, especially in residential applications. Thus, if water use patterns dictate that different rates should be established for the commodity and demand components, historical water use patterns and good judgment should be used in setting these rates for the small water utility.

The fire protection cost component includes costs for fire hydrants, service lines, and other facilities required to provide an adequate water supply in the event of a fire. In public systems the simplest method of recovering these costs is to spread them equally among all who benefit from the public fire protection system. In the case of private fire protection systems, costs should be paid by the individual user in much the same way as initial service connection fees.

Miscellaneous charges might include a fee for establishing a new account or other one-time costs which should be segregated from the other rate components.

Special rate schedules may also need to be established for certain customers such as those outside of district boundaries. As mentioned in a previous section, you may want to assess a surcharge to these customers to recover a portion of the system capital costs above the actual investment in the form of a rate-of-return.

In the past, multiple block-rate structures have been established for quantity users who have a small demand factor or who place lower excess-capacity requirements on the water system. This rate structure has generally been applied to large industrial users in the form of volume discounts. However, in view of the current trend to encourage water conservation, this rate structure is finding less acceptance in the water industry, and uniform rate structures are finding wider acceptance. This procedure makes it easier to promote conservation of water when every customer pays the same for each gallon of water.

8.43 Rate Design Example

In order to put everything we've learned about rate setting into perspective, let's go through an example of developing a water bill for our typical residential customer.

For purposes of illustration, let's assume that we have a uniform rate structure (no differentiation between commodity and demand volume use) and the average monthly water use is 11,000 gallons for our typical residential user. Volume of use is frequently expressed as cubic feet or hundred cubic feet (ccf), so 11,000 gallons is equal to 14.7 ccf (1 cubic foot = 7.48 gallons).

We calculate the service charge component on the basis of meter size. In this example, we will assume the use of a 5/8-inch residential meter. Before we can assign a service charge, however, we must determine the total number of equivalent 5/8-inch meters in the system. The total number of equivalent meters for our hypothetical water district is 4,231 as shown in Table 8.8. The annual customer cost of service component is $132,900 as given in Table 8.7. To establish the monthly service charge for a 5/8-inch residential meter, divide the annual cost of service by the equivalent number of 5/8-inch meters, then divide this result by 12 as follows:

$$\begin{array}{l}\text{5/8-INCH METER} \\ \text{SERVICE CHARGE}\end{array} = \frac{\$\,132{,}900/\text{yr}}{(4{,}231\text{ meters})\ (12\text{ mo/yr})} = \$2.62\text{ per month per meter}$$

For a 1-inch meter we would multiply the monthly service charge of $2.62 by 1.4 (from Table 8.8), yielding an equivalent 1-inch meter service charge of $3.67 per month.

TABLE 8.8 DETERMINATION OF EQUIVALENT 5/8-INCH METERS[a]

METER SIZE-IN	NUMBER OF METERS	SERVICE[b] RATIO	EQUIVALENT 5/8-INCH METERS
⅝	3,550	1.0	3,550
1	350	1.4	490
1½	90	1.8	162
2	10	2.9	29
TOTAL	4,000		4,231

---

[a] *Adapted from AWWA Manual M-1.*

[b] *Service ratio based on relative cost of meter and service investment.*

The volume charge component is designed to recover commodity- and demand-related costs as given in Table 8.7. This charge is calculated by dividing the revenues to be recovered by total water sales as follows:

Commodity cost	$250,760
Demand cost	264,430
Total volumetric cost	$515,190

Annual water use

= 1,915 acre-feet

= (1,915 ac-ft)(43,560 sq ft/ac)(7.48 gal/cu ft)

= 624,000,000 gallons

= 624,000 • 1000 gallons

= 624,000 thousand gallons

$$\text{VOLUMETRIC RATE} = \frac{\$515{,}190}{624{,}000\text{ thous. gal}} = \$0.83\text{ per thousand gallons}$$

For our typical residential user who consumed 11,000 gallons of water for the month, this volume charge would be

$$\frac{(\$0.83)(11{,}000\text{ gal/mo})}{1{,}000\text{ gal}} = \$9.13\text{ per month.}$$

The public fire protection charge component is designed to recover the demand and direct fire protection costs as given in Table 8.7. The fire protection charge is calculated in a manner similar to that of the service charge based on the annual demand related ($153,350) and direct fire protection costs ($8,650) given in Table 8.7, as follows:

$$\begin{array}{l}\text{⅝-INCH METER FIRE} \\ \text{PROTECTION CHARGE}\end{array} = \frac{\$153{,}350/\text{yr} + \$8650/\text{yr}}{(4{,}321\text{ meters})(12\text{ mo/yr})} = \$3.19\text{ per month per meter}$$

In this example we will assume that there are no miscellaneous charges, so this completes our water bill. Bills for commercial or industrial customers would be calculated in a similar fashion. In summary, our typical residential customer would pay the following monthly water bill:

SERVICE CHARGE	=	$ 2.62
VOLUME CHARGE	=	9.13
FIRE PROTECTION CHARGE	=	3.19
TOTAL MONTHLY CHARGE		$14.94

On the basis of these calculations, the water rates for various sized residential meters can be established as follows:

METER SIZE INCHES	SERVICE RATIO FROM TABLE 8.8	METER SERVICE CHARGE ($2.62/MO) (RATIO)	FIRE PROTECTION CHARGE ($3.19/MO) (RATIO)	TOTAL FIXED CHARGE $/MO
5/8	1.0	$ 2.62	$ 3.19	$ 5.81
1	1.4	3.67	4.47	8.15
1½	1.8	4.72	5.74	10.46
2	2.9	7.60	9.25	16.85

Therefore, monthly residential charges would be the total fixed charge based on meter size plus a volumetric charge of $0.83 per thousand gallons used.

In our example water district Table 8.1 indicates that there are two industrial water users and the number of commercial and miscellaneous customers are not identified. If the industrial and commercial users have demands similar to the demands of residential customers, the fixed charges should be based on meter size and the volumetric charge the same as for residential customers.

8.44 Typical Rate Structure

Most water districts use a rate structure similar to the one developed in the previous section with a fixed charge plus a volumetric charge. Very often the charges are rounded upwards to the nearest 10 cents, 25 cents, 50 cents or a dollar for ease of computation and to generate some surplus revenue for a reserve fund. Some water districts have a minimum charge and the first 1500 gallons or 200 cubic feet of water used per month are included in this charge with an additional volumetric charge for consumption above the minimum level.

Typical charges for a small water district are listed below.

WATER CUSTOMER **No. Gallons**	**$ Rate/1000 Gallons**	**Base Charge**
RESIDENTIAL -		
⅝ inch meter		
First 1000 gallons		$ 6.00
Additional gallons	$ 0.80	
CLINIC		
First 5000 gallons		30.00
Additional gallons	1.20	
ELEMENTARY SCHOOLS		
First 10,000 gallons		45.00
Additional gallons	1.20	
COMMERCIAL		
Restaurants		
First 5000 gallons		30.00
Additional gallons	1.20	
Other Commercial, First 1000 gallons		
1.0 inch or smaller		10.00
1.01 to 2.0 inch		13.25
3.0 inch		16.50
4.0 inch		26.50
5.0 inch		34.75
6.0 inch		46.50
Additional gallons	0.80	

In addition to water usage fees, water districts usually also have a list of other important fees or charges to cover the costs of managing the water supply system. Typical other charges are listed below:

GUARANTEE DEPOSIT	
Single family residences	$ 75.00
Commercial accounts	150.00
MISCELLANEOUS CHARGES	
Transfer fee	25.00
Service call (after hours)	20.00 per call
Turn on fee (after shut off for delinquent account)	35.00
WATER CONNECTION CHARGES (New Installation)	
Capital improvement fee	$1000.00
Water main front footage charge	5.00 per foot
Water service meter charge	Cost of meter plus 15%
Water main tap-in charge	100.00

8.45 Very Small System Example

To illustrate the application of the concepts presented in this chapter, a rate structure will be developed for a very small water supply system.

1. Determine the service area statistics similar to Table 8.1.

Sources of Supply	2 wells with hydropneumatic tanks and one storage tank
Customers (services)	200
Population	500 people
Average daily consumption	50,000 gallons per day

2. Estimate the annual revenue needs based on current and expected expenses (Table 8.3).

O & M EXPENSES	
Power (pumping, lights)	$ 1,000.00
Chemicals (chlorine)	700.00
Salaries	25,000.00
Materials and supplies	5,000.00
Vehicles (gas, oil, tires)	1,000.00
Administration (secretarial, bookkeeping)	20,000.00
Utilities (phone, heat)	500.00
Office rent	1,800.00
DEBT SERVICE (from bookkeeper)	5,000.00
REPAIR, REPLACEMENT, RESERVE	6,000.00
Total Revenue Requirement =	$66,000.00

3. The next step is to allocate the costs (Table 8.5, allocation of O & M expenses, Table 8.6, allocation of plant value and other capital facilities, and Table 8.7, overall allocation of cost of service). Assign the last three O & M expense items to the customer (administration, $20,000, + utilities, $500, + rent, $1,800 = $22,300) because these are not costs directly related to the production of water.

ITEM	TOTAL	COMMODITY AND DEMAND	CUSTOMER
O & M EXPENSES	55,000	32,700	22,300
DEBT SERVICE	5,000	5,000	—
REPAIR, REPLACEMENT, RESERVE	6,000	6,000	—
TOTAL COSTS	66,000	43,700	22,300

4. Determine the monthly meter service charge.

$$\text{Meter Service Charge, \$/mo} = \frac{\text{Customer Charge, \$/yr}}{(\text{Number of Meters})(12\text{ mo/yr})}$$

$$= \frac{\$22{,}300/\text{yr}}{(200\text{ meters})(12\text{ mo/yr})}$$

$$= \$10.29/\text{mo}$$

5. Determine the monthly volumetric water charge.

$$\text{Total Annual Water Use, 1000 gallons/yr} = (\text{Average daily use, GPD})(365\text{ days/yr})$$

$$= (50{,}000\text{ gal/day})(365\text{ days/yr})$$

$$= 18{,}250{,}000\text{ gallons/yr}$$

$$= 18{,}250\text{ thousand gallons/yr}$$

$$\text{Volumetric Water Charge, \$/1000 gal} = \frac{\text{Total Commodity and Demand Cost, \$/yr}}{\text{Total Water Use, 1000 gal/yr}}$$

$$= \frac{\$43{,}700/\text{yr}}{18{,}250\text{ thousand gallons/yr}}$$

$$= \$2.40\text{ per thousand gallons}$$

On the basis of these calculations, the customers for this very small water district will pay $10.30 per month per meter plus $2.40 per thousand gallons of water used.

8.5 ADMINISTRATION OF RATES AND CHARGES

8.50 Recordkeeping

As described in Section 8.41, good recordkeeping is the basis for setting accurate water rates. A good historical data base of customers' water use will provide the basis for allocation of costs to appropriate users. While this has historically been done manually, the current availability of low cost personal computer systems puts automation of many manual bookkeeping functions within the grasp of all water utilities.

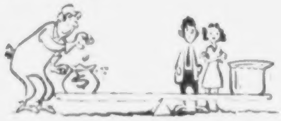
In order to automate your recordkeeping functions as they relate to customer billing, you will need to develop a simple data-base management system that will create tables similar to those illustrated in this chapter. This can be readily accomplished by use of standard spreadsheet software programs which are available in the marketplace at a cost of $300 to $400. Hardware including a personal computer, data storage system, and a printer can be purchased for under $5,000.

To assist the small utility in automating their recordkeeping system, a starter kit consisting of diskette software and instructions is available from the author at a nominal charge.[9] This software can be used on most IBM PC[10] compatible computers which are capable of using LOTUS 1,2,3[11] spreadsheet software.

8.51 Presenting Rates to the Rate Payer

If you have followed the procedures properly up to this point, then presenting your rate needs to the rate payer should not be a problem, but a rather routine matter.

An important aspect in presenting revenue needs to the rate payer is having the ability to justify your system's revenue needs. This is best accomplished by practicing sound financial management and being able to back up your needs with factual records.



In making rate increase presentations to an elected Board of Directors or other elected officials at a public hearing, it is helpful to prepare illustrations of the utility's needs in the form of charts and graphs which state the following information clearly and simply:

- Recent cost performance of utility (budget comparisons)
- Current revenue requirements vs. projected needs
- Effect of proposed rate increases on typical user groups
- Comparison of proposed rates with other similar water utilities in your area

It is good practice to consider potential rate increases on a regular basis, usually annually. This will promote a stable rate adjustment program and will avoid increasing rates by 15 to 20 percent or more during periods of high inflation or greater demand on utility funds. The latter sometimes occurs when rates are not adjusted for multiple-year periods. The consumer expects utility costs to rise moderately over time, but significant one-time bumps in rates every 3 or 4 years can be judged by the consumer to reflect poor fiscal management.

8.6 ACKNOWLEDGMENT

Material in this chapter was reviewed by Leonard Ainsworth, Mike Cherniak and Dave Davidson. Their contributions are greatly appreciated.

8.7 ADDITIONAL READING

The following list of American Water Works Association publications may be obtained by contacting Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235.

1. *WATER RATES* (M1), Order No. 30001. Price to members, $13,00; nonmembers, $16.00.
2. *WATER RATES AND RELATED CHARGES* (M26), Order No. 30026. Price to members, $11.00; nonmembers, $14.00.
3. *MANAGING WATER RATES AND FINANCES,* Order No. 20207. Price to members, $17.50; nonmembers, $22.00.
4. *WATER RATES: AN EQUITABLE CHALLENGE,* AWWA Seminar Proceedings, Order No. 20172. Price to members, $13.00; nonmembers, $16.00.
5. *DEVELOPING WATER RATES,* AWWA Seminar Proceedings, Order No. 20124. Price to members, $7.00; nonmembers, $8.50.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 425.

8.3A Who would be included in a commercial customer class?

8.3B What is a connection fee?

8.4A Who uses more water—metered or unmetered customers?

8.5A What factors should be presented to officials when making a rate increase presentation?

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[9] *James D. Beard, 40859 Ondina Court, Fremont, CA 94539.*

[10] *Trademark of IBM Corporation.*

[11] *Trademark of Lotus Development Corporation.*

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. SETTING WATER RATES FOR SMALL UTILITIES

Please write the answers to these questions in your notebook. The purpose of these questions is to indicate to you how well you understand the material in this chapter.

1. How can water rates be set which accurately reflect the cost of service for each customer?
2. How can future needs be estimated when setting water rates?
3. What is the difference between establishing a revenue base on a cash basis or a utility basis?
4. What is the difference between the "commodity-demand method" and the "base-extra-capacity method" of allocating costs to water users?
5. What is the greatest advantage of the "base-extra-capacity method" of allocation?
6. What factors would you consider in determining the customer classes for water rates?
7. What is the difference between multiple block-rate structures and uniform rate structures?
8. Why is it thought to be a good practice to consider rate increases on a regular basis, usually annually?

SUGGESTED ANSWERS

Chapter 8. SETTING WATER RATES FOR SMALL UTILITIES

Answers to questions on page 416.

8.0A The goals of a fair water rate setting program are to determine rates on a "cost basis" and be "nondiscriminatory" to all users.

8.0B Operation and maintenance expenses are the costs of actually operating and maintaining facilities and include power, salaries and fringe benefits, treatment chemicals and supplies and distribution system costs.

8.1A Capital costs that must be covered by revenue include costs of associated investment, debt service, and also replacement, expansion and improvement of facilities.

8.1B The two general components of inflation which will affect setting of rates and charges are the Consumer Price Index (CPI) and the Construction Cost Index (CCI). The CPI should be applied to general O & M expense items such as labor, materials and supplies. The CCI is used for estimating future construction-related capital improvement costs.

8.1C The costs associated with a water distribution system include storage, distribution, pumping, capital and O & M expenses.

Answers to questions on page 419.

8.2A Utility service cost categories used to distribute costs using the commodity-demand method include (1) commodity, (2) demand, (3) customer, and (4) public fire protection.

8.2B A commodity cost is an expense directly related to the amount of water use. Examples of commodity costs are water costs, power and chemical costs, and labor costs for operating and maintaining the water system.

8.2C A demand cost is an expense associated with providing facilities to meet peak rates of use. Examples of demand costs are storage facilities sized to meet peak demands, transmission and distribution mains, pumping, peaking wells, and some treatment costs.

8.2D A customer cost is the cost of providing service to customers regardless of the amount of water used. Customer costs include meter maintenance, meter reading, customer accounting, and collection costs.

Answers to questions on page 424.

8.3A A commercial customer class includes non-industrial, business, and service-type enterprises.

8.3B A connection fee is an upfront fee paid by new users connecting to the system to cover capital costs to provide service to their property.

8.4A Unmetered customers tend to use more water than metered customers.

8.5A When making a rate increase presentation, illustrate the utility's needs in the form of charts and graphs which simply state the following:

1. Recent cost performance of utility (budget comparisons),
2. Current revenue requirements vs. projected needs,
3. Effect of proposed rate increase on typical user groups, and
4. Comparison of proposed rates with other comparable water utilities in your area.

OBJECTIVE TEST

Chapter 8. SETTING WATER RATES FOR SMALL UTILITIES

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple-choice questions.

1. Important facts regarding a service area when setting water rates include
    1. Diameters of water mains.
    2. Miles of water mains.
    3. Number of customers (services).
    4. System capacity.
    5. Water use categories.
2. Revenue needs that must be considered when setting rates include
    1. Chemical costs.
    2. Debt service.
    3. Income from payments by customers.
    4. O & M expenses.
    5. Rehabilitation costs.
3. Which items should be considered when forecasting future expenditures?
    1. Billing procedures
    2. Future financing requirements
    3. Growth rate
    4. Inflation
    5. Revenue sources
4. Operation and maintenance expense items include
    1. Capital expense.
    2. Debt service.
    3. Materials and supplies.
    4. Power costs.
    5. Salaries.
5. Commodity costs include
    1. Chemical costs.
    2. Customer costs.
    3. Demand costs.
    4. Power costs.
    5. Purchased water costs.
6. General customer classes used by many water utilities include
    1. Commercial.
    2. Industrial.
    3. Public agencies.
    4. Residential.
    5. Unaccounted for.
7. In distributing costs to customers, special consideration should be given to
    1. Average use.
    2. Customers outside district boundaries.
    3. Demand patterns.
    4. Interruptible service.
    5. Wholesale customers.
8. Overall water rates consist of which components?
    1. Fire protection charge
    2. O & M charge
    3. Overhead charge
    4. Service charge
    5. Volume charge

End of Objective Test

APPENDIX

Final Examination

How to Solve Small Water System
Arithmetic Problems

Water Abbreviations

Water Words

Subject Index

SMALL WATER SYSTEM OPERATION AND MAINTENANCE

FINAL EXAMINATION

AND

SUGGESTED ANSWERS

This final examination was prepared TO HELP YOU review the material in this manual. The questions are divided into four types:

1. True-False,
2. Multiple Choice,
3. Short Answers, and
4. Problems.

To work this examination:

1. Write the answers to each question in your notebook.
2. After you have worked a group of questions (you decide how many), check your answers with the suggested answers at the end of this exam, and
3. If you missed a question and don't understand why, reread the material in this manual.

You may wish to use this examination for review purposes when preparing for civil service and certification examinations.

Since you have already completed this course, you do not have to send your answers to California State University, Sacramento.

True — False

1. Small water system operators are responsible for the drinking water of their community.
   1. True
   2. False
2. Chlorination of drinking water is the most common means of disinfection used to protect the public's health.
   1. True
   2. False
3. An amber color in water could indicate the presence of humic substances which could later be converted into trihalomethanes.
   1. True
   2. False
4. Coliforms are used to measure specific disease-producing organisms in drinking water.
   1. True
   2. False
5. Storage of raw water in lakes, ponds or reservoirs hurts the operator by slowing the rate of change in water quality due to storms and other factors.
   1. True
   2. False
6. Incrusting waters are usually acidic while corrosive waters are usually alkaline.
   1. True
   2. False
7. Bacterial growths and slime deposits can be removed from well screens by chlorine treatment.
   1. True
   2. False
8. The colder the water, the faster the coagulation chemical reactions.
   1. True
   2. False
9. Cold water requires shorter chlorine disinfection time than warm water.
   1. True
   2. False
10. Chlorine gas used for disinfection tends to increase the pH of water.
    1. True
    2. False
11. Chlorine reacts with inorganic matter to form chlororganic compounds, including trihalomethanes.
    1. True
    2. False
12. A cigarette can ignite hydrogen gas from the fluid of a battery.
    1. True
    2. False
13. Before attempting to work on electrical motors, be sure to lock out and tag all of the electrical switches.
    1. True
    2. False
14. Correct lab procedures can produce useful results from improperly calibrated lab equipment.
    1. True
    2. False
15. Never pipet chemical reagent solutions or unknown water samples by mouth.
    1. True
    2. False

Multiple Choice

1. Responsibilities of water supply system operators include
   1. Being sure that adequate amounts of water and pressure are available during times of emergency.
   2. Building water supply facilities to collect, store, transport and treat water.
   3. Designing water supply facilities to distribute water to people and industries.
   4. Insuring that safe and pleasant drinking water is delivered to everyone's tap.
   5. Making water supply facilities do their intended job.
2. Health authorities encourage the use of reclaimed wastewater for
   1. Drinking water.
   2. Greenbelt irrigation.
   3. Industrial reuse.
   4. Landscape impoundments.
   5. Municipal swimming pools.
3. When conducting a sanitary survey, sources of waste discharges that must be investigated include
   1. Acid waters from mines.
   2. Agricultural drain waters.
   3. Industrial wastes.
   4. Oil field brines.
   5. Springs.
4. A check valve must
   1. Be able to withstand hydraulic shock loads.
   2. Be easily screwed watertight.
   3. Check the flow in both directions.
   4. Close watertight.
   5. Have a low head loss.
5. Records that should be kept regarding a well include
   1. Accurate data on pump repairs and causes.
   2. Length of time pumping.
   3. Number of drill bits used.
   4. Time required to drill well.
   5. Well depth measurements before and after pumping.
6. Short-circuiting in sedimentation basins depends on
   1. Alkalinity of water.
   2. Backflow prevention devices.
   3. Inlet arrangements of tank.
   4. Jar test results.
   5. pH of water.
7. Excessive amounts of iron and manganese in drinking waters are objectionable because they
   1. Cause corrosion of pipes.
   2. Cause foul tastes and odors.
   3. Consume excessive amounts of soap.
   4. Encourage growth of iron bacteria.
   5. Stain clothes.
8. Inorganic reducing chemicals found in source waters that react rapidly with chlorine include
   1. Ammonia.
   2. Calcium chloride.
   3. Hydrochloric acid.
   4. Hydrogen sulfide.
   5. Sodium chloride.
9. Which of the following precautions would you take when shutting down a hypochlorinator for a short duration?
   1. Lock out circuits
   2. Obtain another hypochlorinator
   3. Turn off gas
   4. Turn off hypochlorinator
   5. Turn off water supply pump
10. Important aspects of a safety program include
    1. Conducting regular safety programs.
    2. Keeping public informed of utility's safety record.
    3. Maintaining industrial accident statistics.
    4. Making operators aware of unsafe acts.
    5. Preventing maintenance records from getting lost.
11. Good safety practices for operators using boats include
    1. Annual safety inspection.
    2. Flotation device for each occupant.
    3. Only one person in the boat.
    4. Overloading the boat.
    5. Using the boat on stormy days.
12. Fires involving zinc or sodium should be extinguished by the use of
    1. Fine dry soda ash.
    2. Foam.
    3. Graphite.
    4. Sand.
    5. Water.
13. The greatest errors in laboratory tests are frequently caused by
    1. Improper sampling.
    2. Lack of enough mixing during testing.
    3. Poor sample preservation.
    4. Using improper laboratory techniques.
    5. Using old reagents.
14. Approved methods for measuring chlorine residual include
    1. Amperometric titration.
    2. DPD colorimetric.
    3. DPD titrimetric.
    4. Nephelometric titration.
    5. Orthotolidine colorimetric.
15. Additional tests that can be performed to improve the interpretation of jar test results include
    1. Alkalinity.
    2. Chlorine demand.
    3. Filterability.
    4. pH.
    5. Turbidity.

Short Answers

1. What does a water supply system operator do?
2. How would you respond to a telephone call from a person complaining about the quality of their drinking water?
3. How are the energy crisis and water shortage linked together?
4. Why are coliform bacteria used to measure the bacteriological quality of water?

5. What is the first priority for operating a water treatment plant?
6. How can an operator protect an aquifier?
7. What is the purpose of the well-casing vent?
8. How can corrosion be monitored in a water main?
9. What factors influence the effectiveness of chlorine when used to disinfect drinking water?
10. What is breakpoint chlorination?
11. How can water mains be kept clean during construction and repair?
12. List the typical locations where a water utility operator should monitor atmospheric conditions before entry.
13. What is the job of the standby person outside a confined space work area?
14. List the items that should be inspected during the safety inspection of a fixed ladder.
15. What information should be recorded when a sample is collected?

Problems

1. Convert a flow of GPM to MGD.
2. Convert a flow of 60 GPD to milliliters per minute.
3. Convert a flow of 100 mL/min to GPD.
4. Determine a chlorinator setting in pounds per 24 hours to treat a flow of 0.90 MGD with a chlorine dose of 2.5 mg/L.
5. A rectangular settling basin 25-feet long, 15-feet wide and the water is 8-feet deep treats a flow of 250,000 gallons per day. Estimate the detention time in hours in the basin for this flow.
6. A 20-foot wide by 24-foot long sand filter treats a flow of 1000 GPM. Calculate the filtration rate in gallons per minute per square foot.
7. What should be the chlorine dose of a water that has a chlorine demand of 1.3 mg/*L* if a residual of 0.4 mg/*L* is desired?
8. What should be the setting on a chlorinator in pounds per 24 hours if a pump usually delivers approximately 520 gallons per minute and the desired chlorine dose is 2.5 mg/*L*?
9. Estimate the desired strength (as a percent chlorine) of a hypchlorite solution being pumped by a hypochlorinator that delivers 100 gallons per day. The water being treated requires a chlorine feed rate of 19 pounds of chlorine per day.
10. A water treatment plant has seventeen 150-pound chlorine cylinders in storage. The plant uses an average of 127 pounds of chlorine per day. How many days' supply of chlorine is in storage?
11. Convert the temperature of water from 67° Fahrenheit to degrees Celsius.
12. Convert the temperature of water from 13° Celsius to degrees Fahrenheit.
13. Results from the MPN test on raw water were as follows:

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
MPN/100 m*L*	177	43	41	22	13	58	33

Estimate the mean and median of the data in MPN/100 m*L*.

14. Estimate the desired strength (as a percent chlorine) of a hypochlorite solution being pumped by a hypochlorinator that delivers 50 gallons per day. The water being treated requires a chlorine feed rate of four pounds of chlorine per day.
15. How many gallons of water must be added to five gallons of a five percent hypochlorite solution to produce a 0.5 percent hypochlorite solution?

SUGGESTED ANSWERS FOR FINAL EXAMINATION

True — False

1. True	Small water system operators are responsible for the drinking water of their community.
2. True	Chlorination of drinking water is the most common means of disinfection used to protect the public's health.
3. True	An amber color in water could indicate the presence of humic substances which could later be converted into trihalomethanes.
4. False	Coliforms are used to measure the bacteriological quality of drinking water, but not specific disease-producing organisms.
5. False	Storage of raw water in lakes, ponds or reservoirs HELPS the operator by slowing the rate of change in water quality due to storms and other factors.
6. False	Incrusting waters are usually alkaline while corrosive waters are usually acidic.
7. True	Bacteriological growths and slime deposits can be removed from well screens by chlorine treatment.
8. False	The colder the water, the slower the coagulation chemical reactions.
9. False	Cold water requires longer disinfection time than warm water.
10. False	Chlorine gas used for disinfection tends to decrease the pH of water.
11. False	Chlorine reacts with organic matter to form chlororganic compounds, including trihalomethanes.
12. True	A cigarette can ignite hydrogen gas from the fluid in a battery.
13. True	Before attempting to work on electrical motors, be sure to lock out and tag all electrical switches.

14. False	Correct lab procedures will not produce useful results from improperly calibrated lab equipment.
15. True	Never pipet chemical reagent solutions or unknown water samples by mouth.

Multiple Choice

1. 1,4,5	Responsibilities of water supply system operators include being sure adequate amounts of water and pressure are available, delivering safe and pleasant drinking water, and making facilities do their job. Building and designing are not operator's responsibilities.
2. 2,3,4	Health authorities encourage the use of reclaimed wastewater for greenbelt irrigation, industrial reuse and landscape impoundments, but not for drinking water or municipal swimming pools.
3. 1,2,3,4	When conducting a sanitary survey, sources of waste discharges that must be investigated include acid waters from mines, agricultural drain waters, industrial wastes, and oil field brines. Springs may be a source of drinking water, not wastes.
4. 1,4,5	A check valve must be able to withstand hydraulic shock loads, close watertight, and have a low head loss.
5. 1,2,5	Records that should be kept regarding a well include accurate data on pump repairs and causes, length of time pumping, and well depth measurements before and after pumping.
6. 3	Inlet arrangements of tank is the only factor listed which influences short-circuiting in a sedimentation basin; however, there are other factors such as outlet arrangements and density currents.
7. 2,4,5	Excessive amounts of iron and manganese in drinking waters are objectionable because they cause foul tastes and odors, encourage growth of iron bacteria, and stain clothes.
8. 1,4	Inorganic reducing compounds found in source waters that react rapidly with chlorine include ammonia and hydrogen sulfide.
9. 1,4,5	Precautions that should be taken when shutting down a hypochlorinator for a short duration include locking out circuits, turning off hypochlorinator and turning off water supply pump.
10. 1,4	Important aspects of a safety program include conducting regular safety programs and making operators aware of unsafe acts.
11. 1,2	Good safety practices for operators using boats include annual safety inspection and flotation device for each occupant.
12. 1,3,4	Fires involving sodium or zinc should be extinguished by the use of fine dry soda ash, graphite or sand.
13. 1,2,3	The greatest errors in laboratory tests are frequently caused by improper sampling, lack of enough mixing during testing, and poor sample preservation.
14. 1,2,3	Approved methods for measuring chlorine residual include amperometric titration, DPD colorimetric and DPD titrimetric.
15. 1,2,3,4,5	Additional tests that can be performed to improve the interpretation of jar test results include alkalinity, filterability, pH and turbidity.

Short Answers

1. Water supply system operators keep the system operating efficiently to deliver safe and pleasant water. They inspect the system to keep the water flowing today and in the future. Physically, they have manual and power-operated equipment to help them do the job, including repairs and minor additions to the system. Other jobs include lubricating and maintaining equipment, collecting water samples, and recordkeeping.
2. Whenever someone phones you with a complaint, record all of the necessary information (name, date, location, and phone number) and have the complaint thoroughly investigated. Be sure to notify the person who complained the results of your investigation and what corrective action was or will be taken.
3. The energy crisis and water shortage are linked together because (1) with falling groundwater levels, more energy is required to pump from deeper levels, and (2) water projects that use large amounts of electricity to pump water over long distances are requiring water users to pay increased water rates to cover higher energy costs.
4. Coliforms are used to measure the bacteriological quality of drinking water because the test indicates the fecal contamination where specific disease-producing organisms are not easily isolated and identified.
5. The first priority for operating a water treatment plant is the production of a safe drinking water, one that is free of harmful bacteria and toxic materials.
6. An operator can protect an aquifier by watching for any construction and other activities that might result in wastes entering the groundwater stream.
7. The purpose of the well-casing vent is to prevent vacuum conditions inside a well by admitting air into the well during the drawdown period when the well pump is first started. The well-casing vent also serves to prevent pressure buildup inside the well casing by allowing excess air to escape during the well recovery (refilling) period after the well pump shuts off.
8. Corrosion can be monitored in a water main by examining specimens of the actual pipeline material. This inspection is easy if sections of pipe can be removed periodically. Alternatively small specimens of the pipeline materials can be mounted in the flowing water and periodically removed for inspection.

9. Factors influencing the effectiveness of chlorine when used to disinfect drinking water include pH, temperature, turbidity, organic and inorganic matter, reducing agents and numbers and types of microorganisms.
10. Breakpoint chlorination is the addition of chlorine to water until the chlorine demand has been satisfied and further additions of chlorine results in a free available residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.
11. Water mains can be kept clean during construction and repair by keeping material such as dirt, construction materials, animals, rodents and dirty water out of mains. Inspecting the pipes when laid, keeping trenches dry and installing watertight plugs all help to keep pipes clean.
12. Typical locations where a water utility operator should monitor atmospheric conditions before entry include underground regulator vaults, solution vaults, valve boxes, manholes, elevated tanks, covered tanks, underground tanks, trenches, drained clear wells, and other covered tanks, and all other confined spaces.
13. The job of the standby person outside a confined space work area is to check continuously on the status of personnel working in the confined space. Should a person working in the confined space be rendered unconscious due to asphyxiation or lack of oxygen, the standby at the surface could enter into the space by:
    1. Securing a back up rescue person, and
    2. Putting on the correct type of respiratory protective equipment.
14. A safety inspection of a fixed ladder should include checking for:
    1. Loose, worn and damaged rungs on side rails,
    2. Corroded or damaged parts of the security door,
    3. Corroded bolts or rivet heads where ladder is affixed to tank, and
    4. Defects in climbing devices, including loose or damaged carrier rails or cables.
15. When collecting a sample, record the sample location, date and time of collection, name of collector, and any other pertinent information.

Problems

1. Convert a flow of 300 GPM to MGD.

Known	Unknown
Flow, GPM = 300 GPM	Flow, MGD

Convert the flow of 300 GPM to MGD.

$$\text{Flow, MGD} = \frac{(\text{Flow, GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$

$$= \frac{(300\ \text{GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$

$$= 0.43\ \text{MGD}$$

2. Convert a flow of 60 GPD to milliliters per minute.

Known	Unknown
Flow, GPD = 60 GPD	Flow, mL/min

Convert flow from 60 GPD to milliliters per minute.

$$\text{Flow, m}L\text{/min} = \frac{(\text{Flow, GPD}(3.785\ L\text{/gal})(1000\ \text{m}L/L)}{(24\ \text{hr/day})(60\ \text{min/hr})}$$

$$= \frac{(60\ \text{gal/day})(3.785\ L\text{/gal})(1000\ \text{m}L/L)}{(24\ \text{hr/day})(60\ \text{min/hr})}$$

$$= 158\ \text{m}L\text{/min}$$

3. Convert a flow of 100 mL/min to GPD.

Known	Unknown
Flow, mL/.min = 100 mL/min	Flow, GPD

Convert 100 mL/min to GPD.

$$\text{Flow, GPD} = \frac{(\text{Flow, m}L\text{/min})(60\ \text{min/hr})(24\ \text{hr/day})}{(1000\ \text{m}L/L)(3.785\ L\text{/gal})}$$

$$= \frac{(100\ \text{m}L\text{/min})(60\ \text{min/hr})(24\ \text{hr/day})}{(1000\ \text{m}L/L)(3.785\ L\text{/gal})}$$

$$= 38\ \text{GPD}$$

4. Determine a clorinator setting in pounds per 24 hours to treat a flow of 0.90 MGD with a chlorine dose of 2.5 mg/L.

Known	Unknown
Flow, MGD = 0.90 MGD	Chlorinator Setting, lbs/24 hours
Chlorine Dose, mg/L = 2.5 mg/L	

Determine the chlorinator setting in pounds per 24 hours or pound per day.

$$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\ \text{lbs/gal})$$

$$= (0.90\ \text{MGD})(2.5\ \text{mg/}L)(8.34\ \text{lbs/gal})$$

$$= 19\ \text{lbs/day}$$

5. A rectangular settling basin 25-feet long, 15-feet wide and the water is 8-feet deep treats a flow of 250,000 gallons per day. Estimate the detention time in hours in the basin for this flow.

Known	Unknown
Length, ft = 25 ft	Detention Time, hr
Width, ft = 15 ft	
Depth, ft = 8 ft	
Flow, GPD = 250,000 GPD	

1. Calculate the basin volume in gallons.

$$\text{Basin Volume, gal} = (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})(7.48\ \text{gal/cu ft})$$

$$= (25\ \text{ft})(15\ \text{ft})(8\ \text{ft})(7.48\ \text{gal/cu ft})$$

$$= 22{,}440\ \text{gal}$$

2. Calculate the detention time in hours.

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{(22{,}400\ \text{gal})(24\ \text{hr/day})}{250{,}000\ \text{GPD}}$$

$$= 2.2\ \text{hr}$$

6. A 20-foot wide by 24-foot long sand filter treats a flow of 1000 GPM. Calculate the filtration rate in gallons per minute per square foot.

Known	Unknown
Width, ft = 20 ft	Filtration Rate, GPM/sq ft
Length, ft = 24 ft	
Flow, GPD = 1000 GPM	

Determine the filtration rate in gallons per minute per square foot.

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$= \frac{1000\ \text{GPM}}{(20\ \text{ft})(24\ \text{ft})}$$

$$= 2.1\ \text{hr}$$

7. What should be the chlorine dose of a water that has a chlorine demand of 1.3 mg/*L* if a residual of 0.4 mg/*L* is desired?

Known	Unknown
Chlorine Demand, mg/*L* = 1.3 mg/*L*	Chlorine Dose, mg/*L*
Chlorine Residual, mg/*L* = 0.4 mg/*L*	

Calculate the chlorine dose in milligrams per liter.

$$\text{Chlorine Dose, mg}/L = \text{Chlorine Demand, mg}/L + \text{Chlorine Residual, mg}/L$$

$$= 1.3\ \text{mg}/L + 0.4\ \text{mg}/L$$

$$= 1.7\ \text{mg}/L$$

8. What should be the setting on a chlorinator in pounds per 24 hours if a pump usually delivers approximately 5[illegible]0 gallons per minute and the desired chlorine dose is 2.5 mg/*L*?

Known	Unknown
Pump Flow, GPM = 520 GPM	Chlorinator Setting, lbs Chlorine/24 hrs
Chlorine, Dose, mg/*L* = 2.5 mg/*L*	

1. Convert the flow from GPM to MGD.

$$\text{Flow, MGD} = \frac{(\text{Flow, GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$

$$= \frac{(520\ \text{GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$

$$= 0.75\ \text{MGD}$$

2. Calculate the chlorinator setting in pounds per 24 hours.

$$\text{Chlorinator Setting, lbs/24 hrs} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.75\ \text{MGD})(2.5\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 16\ \text{lbs/24 hrs}$$

9. Estimate the desired strength (as a percent chlorine) of a hypochlorite solution being pumped by a hypochlorinator that delivers 100 gallons per day. The water being treated requires a chlorine feed rate of 19 pounds of chlorine per day.

Known	Unknown
Hypochlorinator Flow, GPD = 100 GPD	Hypochlorite Strength, %
Chlorine Required, lbs/day = 19 lbs/day	

Estimate the desired hypochlorite strength as a percent chlorine.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, GPD})(8.34\ \text{lbs/gal})}$$

$$= \frac{(19\ \text{lbs/day})(100\%)}{(100\ \text{gal/day})(8.34\ \text{lbs/gal})}$$

$$= 2.3\%$$

10. A water treatment plant has seventeen 150-pound chlorine cylinders in storage. The plant uses an average of 127 pounds of chlorine per day. How many days' supply of chlorine is in storage?

Known		Unknown
Chlorine Cylinders	17 cylinders	Supply of Chlorine, days
Cylinders Wt. lbs/cyl	150 lbs/cyl	
Ave Use, lbs/day	127 lbs/day	

$$\text{Supply of Chlorine, days} = \frac{(\text{Cylinder Wt, lbs/cyl})(\text{No. of cylinders})}{\text{Ave Use, lbs/day}}$$

$$= \frac{(150\ \text{lbs/cyl})(17\ \text{cylinders})}{127\ \text{lbs/day}}$$

$$= 20\ \text{days}$$

11. Convert the temperature of water from 67° Fahrenheit to degrees Celsius.

Known	Unknown
Temp, °F = 67°F	Temp, °C

Change 67°F to degrees Celsius.

$$\text{Temperature, °C} = \frac{5}{9}(\text{°F} - 32\text{°F})$$

$$= \frac{5}{9}(67\text{°F} - 32\text{°F})$$

$$= 19.4\text{°C}$$

12. Convert the temperature of water from 13° Celsius to degrees Fahrenheit.

Known	Unknown
Temp, °C = 13°C	Temp, °F

Change 13°C to degrees Fahrenheit.

$$\text{Temperature, °F} = \frac{9}{5}(\text{°C}) + 32\text{°F}$$

$$= \frac{9}{5}(13\text{°C}) + 32\text{°F}$$

$$= 55.4\text{°F}$$

13. Results from the MPN tests on raw water were as follows:

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
MPN/100 m*L*	177	43	41	22	13	58	33

Estimate the mean and median of the data in MPN/100 m*L*.

1. Calculate the mean.

$$\text{Mean, MPN/100 m}L = \frac{\text{Sum of All MPNs}}{\text{Number of MPNs}}$$

$$= \frac{177 + 43 + 41 + 22 + 13 + 58 + 33}{7}$$

$$= \frac{387}{7}$$

$$= 55 \text{ MPN/100 m}L$$

2. Determine the median. Rearrange the data in ascending (increasing) order and select the middle value (three will be smaller and three will be larger in this example).

Order	1	2	3	4	5	6	7
MPN/100 m*L*	13	22	33	41	42	48	177

$$\text{Median, MPN/100 m}L = \text{Middle value of a group of data}$$

$$= 41 \text{ MPN/100 m}L$$

14. Estimate the desired strength (as a percent chlorine) of a hypochlorite solution being pumped by a hypochlorinator that delivers 50 gallons per day. The water being treated requires a chlorine feed rate of four pounds of chlorine per day.

KNOWN	UNKNOWN
Hypochlorinator Flow, GPD = 50 GPD	Hypochlorinator Strength, %
Chlorine Required, lbs/day = 4 lbs/day	

Estimate the desired hypochlorite strength as a percent chlorine.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, gal/day})(8.34 \text{ lbs/gal})}$$

$$= \frac{(4 \text{ lbs/day})(100\%)}{(50 \text{ GPD})(8.34 \text{ lbs/gal})}$$

$$= 0.96\%$$

15. How many gallons of water must be added to five gallons of a five percent hypochlorite solution to produce a 0.5 percent hypochlorite solution?

KNOWN	UNKNOWN
Hypochlorite, gal = 5 gal	Water Added, gal
Desired Hypochlorite, % = 0.5%	
Actual Hypochlorite, % = 5%	

Calculate the gallons of water that must be added to produce a 0.5% hypochlorite solution.

$$\text{Water Added, gal (to hypochlorite solution)} = \frac{(\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Hypo, gal})(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

$$= \frac{(5 \text{ gal})(5\%) - (5 \text{ gal})(0.5\%)}{0.5\%}$$

$$= \frac{25 - 2.0}{0.5}$$

$$= 45 \text{ gallons}$$

APPENDIX

HOW TO SOLVE SMALL WATER SYSTEM ARITHMETIC PROBLEMS

by

Ken Kerri

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HOW TO SOLVE WATER DISTRIBUTION SYSTEM ARITHMETIC PROBLEMS

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OBJECTIVES

HOW TO SOLVE SMALL WATER SYSTEM ARITHMETIC PROBLEMS

After completion of this Appendix, you should be able to do the following:

1. Add, subtract, multiply and divide.
2. List from memory basic conversion factors and formulas, and
3. Solve small water system arithmetic problems.

APPENDIX. HOW TO SOLVE SMALL WATER SYSTEM ARITHMETIC PROBLEMS

A.0 HOW TO STUDY THIS APPENDIX

This appendix may be worked early in your training program to help you gain the greatest benefit from your efforts. Whether to start this appendix early or wait until later is your decision. The chapters in this manual were written in a manner requiring very little background in arithmetic. You may wish to concentrate your efforts on the chapters and refer to this appendix when you need help. Some operators prefer to complete this appendix early so they will not have to worry about how to do the arithmetic when they are studying the chapters. You may try to work this appendix early or refer to it while studying the other chapters.

The intent of this appendix is to provide you with a quick review of the addition, subtraction, multiplication and division needed to work the arithmetic problems in this manual. This appendix is not intended to be a math textbook. There are no fractions because you don't need fractions to work the problems in this manual. Some operators will be able to skip over the review of addition, subtraction, multiplication and division. Others may need more help in these areas. If you need help in solving problems, read Section A.9, "Steps in Solving Problems." Basic arithmetic textbooks are available at every local library or bookstore and should be referred to if needed. Most instructional or operating manuals for pocket electronic calculators contain sufficient information on how to add, subtract, multiply, and divide.

After you have worked a problem involving your job, you should check your calculations, examine your answer to see if it appears reasonable, and if possible have another operator check your work before making any decisions or changes.

A.1 BASIC ARITHMETIC

In this Section we are going to provide you with basic arithmetic problems involving addition, subtraction, multiplication and division. You may work the problems "by hand" if you wish, but we recommend you use an electronic pocket calculator. The operating or instructional manual for your calculator should outline the step-by-step procedures to follow. All calculators use similar procedures, but most of them are slightly different from others.

We will start with very basic, simple problems. Try working the problems and then comparing your answers with the given answers. If you can work these problems, you should be able to work the more difficult problems in the text of this training manual by using the same procedures.

A.10 Addition

$$\begin{array}{r}2\\3\\\hline 5\end{array}\qquad\begin{array}{r}6.2\\8.5\\\hline 14.\end{array}\qquad\begin{array}{r}16.7\\38.9\\\hline 55.6\end{array}\qquad\begin{array}{r}6.12\\38.39\\\hline 44.51\end{array}\qquad\begin{array}{r}43\\39\\34\\38\\39\\37\\29\\\hline 259\end{array}$$

$$\begin{array}{r}2.12\\9.80\\\hline 11.92\end{array}\qquad\begin{array}{r}0.12\\2.0\\\hline 2.12\end{array}\qquad\begin{array}{r}63\\32\\\hline 95\end{array}\qquad\begin{array}{r}120\\60\\\hline 180\end{array}$$

$$\begin{array}{r}4\\7\\2\\\hline 13\end{array}\qquad\begin{array}{r}23\\79\\31\\\hline 133\end{array}\qquad\begin{array}{r}16.2\\43.5\\67.8\\\hline 127.5\end{array}\qquad\begin{array}{r}45.98\\28.09\\114.00\\\hline 188.07\end{array}\qquad\begin{array}{r}70\\50\\40\\80\\\hline 240\end{array}$$

A.11 Subtraction

$$\begin{array}{r}7\\-5\\\hline 2\end{array}\qquad\begin{array}{r}12\\-3\\\hline 9\end{array}\qquad\begin{array}{r}25\\-5\\\hline 20\end{array}\qquad\begin{array}{r}78\\-30\\\hline 48\end{array}\qquad\begin{array}{r}83\\-69\\\hline 14\end{array}$$

$$\begin{array}{r}61\\-37\\\hline 24\end{array}\qquad\begin{array}{r}485\\-296\\\hline 189\end{array}\qquad\begin{array}{r}4.3\\-0.8\\\hline 3.5\end{array}\qquad\begin{array}{r}3.5\\-0.7\\\hline 2.8\end{array}\qquad\begin{array}{r}123\\-109\\\hline -14\end{array}$$

$$\begin{array}{r}8.6\\-8.22\\\hline 0.38\end{array}\qquad\begin{array}{r}11.92\\-3.70\\\hline 8.22\end{array}\qquad\begin{array}{r}27.32\\-12.96\\\hline 14.36\end{array}\qquad\begin{array}{r}3.574\\-0.042\\\hline 3.532\end{array}\qquad\begin{array}{r}75.132\\-49.876\\\hline 25.256\end{array}$$

A.12 Multiplication

(3)(2)[a] = 6 (4)(7) = 28

(10)(5) = 50 (10)(1.3) = 13

(2)(22.99) = 45.98 (6)(19.5) = 117

(16)(17.1) = 273.6 (50)(20,000) = 1,000,000

(40)(2.31) = 92.4 (80)(0.433) = 34.6

(40)(20)(6) = 4,800

(4,800)(7.48) = 35,904

(1.6)(2.3)(8.34) = 30.6912

(0.001)(200)(8.34) = 1.668

(0.785)(7.48)(60) = 352.308

(12,000)(500)(60)(24) = 8,640,000,000 or 8.64×10^9

(4)(1000)(1000)(454) = 1,816,000,000 or 1.816×10^9

NOTE: The term, $\times 10^9$, means that the number is multiplied by 10^9 or 1,000,000,000. Therefore $8.64 \times 10^9 = 8.64 \times 1{,}000{,}000{,}000 = 8{,}640{,}000{,}000$.

---

[a] (3)(2) is the same as $3 \times 2 = 6$.

A.13 Division

$$\frac{6}{3} = 2$$

$$\frac{50}{25} = 2$$

$$\frac{20}{7.1} = 2.8$$

$$\frac{1{,}000{,}000}{17.5} = 57{,}143$$

$$\frac{4{,}000{,}000}{74{,}880} = 53.4$$

$$\frac{80}{2.31} = 34.6$$

$$\frac{250}{17.1} = 14.6$$

$$\frac{48}{12} = 4$$

$$\frac{300}{20} = 15$$

$$\frac{11{,}400}{188} = 60.6$$

$$\frac{861{,}429}{30{,}000} = 28.7$$

$$\frac{1.67}{8.34} = 0.20$$

$$\frac{62}{454} = 0.137$$

$$\frac{4{,}000{,}000}{14.6} = 273{,}973$$

NOTE: When we divide ⅓ = 0.3333, we get a long row of 3s. Instead of the row of 3s, we "round-off" our answer so ⅓ = 0.33. For a discussion of rounding off numbers, see Section A.95, "Significant Figures."

A.14 Multiplication and Division

Many of the problems we work in the waterworks field involve both multiplication and division. Sometimes addition or subtraction is also involved. To work these types of problems:

1. Do all the addition and subtraction above and below the line,
2. Do all the multiplication above and below the line, and
3. Perform the division.

Instructions for your electronic calculator can provide you with the detailed procedures.

$$\frac{(3)(4)}{2} = 6$$

$$\frac{(2+3)(4)}{5} = 4$$

$$\frac{(7-2)(8)}{4} = 10$$

$$\frac{(9)(8)-(6)(6)}{3} = 12$$

$$\frac{(20)}{(0.85)(8.34)} = 2.82$$

$$\frac{(14)(2)}{(13.53-12.98)(8.34)} = 6.10$$

$$\frac{(13)(100)}{(120)(8.34)} = 1.3$$

$$\frac{861{,}429}{(500)(60)} = 28.7$$

$$\frac{64}{(8)(4)} = 2$$

$$\frac{(54)}{(4+2)(3)} = 3$$

$$\frac{48}{(8-3)(4)} = 2.4$$

$$\frac{(16)(6)}{(8)(7)-(4)(4)} = 2.4$$

$$\frac{30-27}{(1.6)(8.34)} = 0.22$$

$$\frac{(4)(1{,}000{,}000)}{74{,}880} = 53.4$$

$$\frac{(0.1)(60)(24)}{3} = 48$$

$$\frac{(12{,}000)(500)(60)(24)}{(4)(1000)(1000)(454)} = 4.76$$

$$\frac{12}{(0.432)(8.34)} = 3.3$$

$$\frac{(274{,}000)(24)}{200{,}000} = 32.88$$

A.15 Actual Problems

Let's look at the last four problems in the previous Section A.14, "Multiplication and Division," as they might be encountered by an operator.

1. To determine the actual chemical feed rate from an alum feeder, an operator collects the alum from the feeder in a bucket for three minutes. The alum in the bucket weighs 0.1 pounds.

Known		Unknown
Weight of Alum, lbs	= 0.1 lbs	Actual Alum Feed, lbs/day
Time, min	= 3 min	

Calculate the actual alum feed rate in pounds per day.

$$\begin{aligned}\text{Actual Alum Feed Rate, lbs/day} &= \frac{(\text{Alum Wt, lbs})(60\ \text{min/hr})(24\ \text{hr/day})}{\text{Time Alum Collected, min}}\\ &= \frac{(0.1\ \text{lbs})(60\ \text{min/hr})(24\ \text{hr/day})}{3\ \text{min}}\\ &= 48\ \text{lbs/day}\end{aligned}$$

2. A solution chemical feeder is calibrated by measuring the time to feed 500 milliliters of chemical solution. The test calibration run required four minutes. The chemical concentration in the solution is 12,000 mg/*L* or 1.2%. Determine the chemical feed in pounds per day.

Known		Unknown
Volume Pumped, m*L*	= 500 m*L*	Chemical Feed, lbs/day
Time Pumped, min	= 4 min	
Chemical Conc., mg/*L*	= 12,000 mg/*L*	

Estimate the chemical feed rate in pounds per day.

$$\begin{aligned}\text{Chemical Feed, lbs/day} &= \frac{(\text{Chem Conc, mg}/L)(\text{Vol Pumped, m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(\text{Time Pumped, min})(1000\ \text{m}L/L)(1000\ \text{mg/gm})(454\ \text{gm/lb})}\\ &= \frac{(12{,}000\ \text{mg}/L)(500\ \text{m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(4\ \text{min})(1000\ \text{m}L/L)(1000\ \text{mg/gm})(454\ \text{gm/lb})}\\ &= 4.76\ \text{lbs/day}\end{aligned}$$

3. A chlorinator is set to feed twelve pounds of chlorine per day to a flow of 300 gallons per minute (0.432 million gallons per day). What is the chlorine dose in milligrams per liter?

Known		Unknown
Chlorinator Feed, lbs/day	= 12 lbs/day	Chlorine Dose, mg/*L*
Flow, MGD	= 0.432 MGD	

Determine the chlorine dose in milligrams per liter.

$$\text{Chlorine Dose, mg/}L = \frac{\text{Chlorinator Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{12\text{ lbs/day}}{(0.432\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 3.3\text{ mg/}L$$

4. Estimate the operating time of a water softening ion exchange unit before the unit needs regeneration. The unit can treat 274,000 gallons of water before the exchange capacity is exhausted. The average daily flow is 200,000 gallons per day.

Known		Unknown
Water Treated, gal	= 274,000 gal	Operating Time, hr
Ave Daily Flow, gal/day	= 200,000 gal/day	

Estimate the operating time of the ion exchange unit in hours.

$$\text{Operating Time, hr} = \frac{(\text{Water Treated, gal})(24\text{ hr/day})}{\text{Ave Daily Flow, gal/day}}$$

$$= \frac{(274{,}000\text{ gal})(24\text{ hr/day})}{200{,}000\text{ gal/day}}$$

$$= 32.9^{*}\text{ hours}$$

---

*We rounded off 32.88 hours to 32.9 hours.

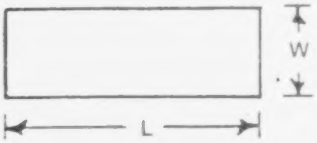
A.2 AREAS

A.20 Units

Areas are measured in two dimensions or in square units. In the English system of measurement the most common units are square inches, square feet, square yards, and square miles. In the metric system the units are square millimeters, square centimeters, square meters, and square kilometers.

A.21 Rectangle

The area of a rectangle is equal to its length (L) multiplied by its width (W).



$$\boxed{A = L \times W}$$

Example: Find the area of a rectangle if the length is 5 feet and the width is 3.5 feet.

$$\begin{aligned} \text{Area, sq ft} &= \text{Length, ft} \times \text{Width, ft} \\ &= 5\text{ ft} \times 3.5\text{ ft} \\ &= 17.5\text{ ft}^2 \\ &= 17.5\text{ sq ft} \end{aligned}$$

Example: The surface area of a settling basin is 330 square feeet. One side measures 15 feet. How long is the other side?

$$A = L \times W$$

$$330\text{ sq ft} = L\text{ ft} \times 15\text{ ft}$$

$$\frac{L\text{ ft} \times 15\text{ ft}}{15\text{ ft}} = \frac{330\text{ ft}^2}{15\text{ ft}}$$ Divide both sides of equation by 15 ft.

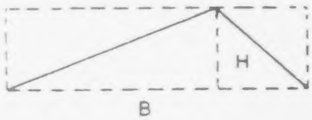
$$L\text{ ft} = \frac{330\text{ ft}^2}{15\text{ ft}}$$

$$= 22\text{ ft}$$

A.22 Triangle

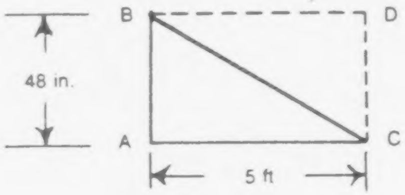
The area of a triangle is equal to one half the base multiplied by the height. This is true for any triangle.

$$\boxed{A = \tfrac{1}{2} B \times H}$$



NOTE: The area of *ANY* triangle is equal to ½ the area of the rectangle that can be drawn around it. The area of the rectangle is B × H. The area of the triangle is ½ B × H.

Example: Find the area of triangle ABC.



The first step in the solution is to make all the units the same. In this case, it is easier to change inches to feet.

$$48\text{ }\cancel{\text{in}} = 48\text{ in} \times \frac{1\text{ ft}}{12\text{ }\cancel{\text{in}}} = \frac{48}{12}\text{ ft} = 4\text{ ft}$$

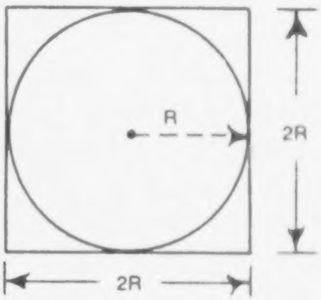
NOTE: All conversions should be calculated in the above manner. Since 1 ft/12 in is equal to unity, or one, multiplying by this factor changes the form of the answer but not its value.

$$\begin{aligned} \text{Area, sq ft} &= \tfrac{1}{2}(\text{Base, ft})(\text{Height, ft}) \\ &= \tfrac{1}{2} \times 5\text{ ft} \times 4\text{ ft} \\ &= \frac{20}{2}\text{ ft}^2 \\ &= 10\text{ sq ft} \end{aligned}$$

NOTE: Triangle ABC is one half the area of rectangle ABCD. The triangle is a special form called a *RIGHT TRIANGLE* since it contains a 90° angle at point A.

A.23 Circle

A square with sides of 2R can be drawn around a circle with a radius of R.



The area of the square is: $A = 2R \times 2R = 4R^2$

It has been found that the area of any circle inscribed within a square is slightly more than ¾ of the area of the square. More precisely, the area of the preceding circle is:

$$A\ \text{circle} = 3\frac{1}{7}R^2 = 3.14\ R^2$$

The formula for the area of a circle is usually written:

$$\boxed{A = \pi R^2}$$

The Greek letter π (pronounced pie) merely substitutes for the value 3.1416.

Since the diameter of any circle is equal to twice the radius, the formula for the area of a circle can be rewritten as follows:

$$A = \pi R^2 = \pi \times R \times R = \pi \times \frac{D}{2} \times \frac{D}{2} = \frac{\pi D^2}{4} = \frac{3.14}{4} D^2 = \boxed{0.785\ D^2}$$

The type of problem and the magnitude of the numbers in a problem will determine which of the two formulas will provide a simpler solution. All of these formulas will give the same results if you use the same number of digits to the right of the decimal point.

Example: What is the area of a circle with a diameter of 20 centimeters?

In this case, the formula using a radius is more convenient since it takes advantage of multiplying by 10.

Area, sq cm = π (R, cm)^2

= 3.14 × 10 cm × 10 cm

= 314 sq cm

Example: What is the area of a clarifier with a 50-foot radius?

In this case, the formula using diameter is more convenient.

Area, sq ft = 0.785 (Diameter, ft)^2

= 0.785 × 100 ft × 100 ft

= 7850 sq ft

Occasionally the operator may be confronted with a problem giving the area and requesting the radius or diameter. This presents the special problem of finding the square root of the number.

Example: The surface area of a circular clarifier is approximately 5000 square feet. What is the diameter?

$A = 0.785\ D^2$, or

Area, sq ft = 0.785 (Diameter, ft)^2

5000 sq ft = $0.785\ D^2$ — To solve, substitute given values in equation.

$\frac{0.785\ D^2}{0.785} = \frac{5000\ \text{sq ft}}{0.785}$ — Divide both sides by 0.785 to find D^2

$D^2 = \frac{5000\ \text{sq ft}}{0.785}$

= 6369 sq ft. Therefore,

D = square root of 6369 sq ft, or

Diameter, ft = $\sqrt{6369\ \text{sq ft}}$

Punch the $\sqrt{\ }$ sign on your calculator and get D, ft = 79.8 ft.

Sometimes it is easier to use a trial and error method of finding square roots. Since 80 × 80 = 6400, we know the answer is close to 80 feet.

Try 79 × 79 = 6241

Try 79.5 × 79.5 = 6320.25

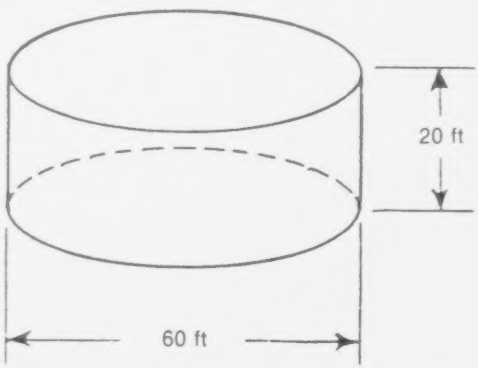
Try 79.8 × 79.8 = 6368.04

The diameter is 79.8 ft, or approximately 80 feet.

A.24 Cylinder

With the formulas presented thus far, it would be a simple matter to find the number of square feet in a room that was to be painted. The length of each wall would be added together and then multiplied by the height of the wall. This would give the surface area of the walls (minus any area for doors and windows). The ceiling area would be found by multiplying length times width and the result added to the wall area gives the total area.

The surface area of a circular cylinder, however, has not been discussed. If we wanted to know how many square feet of surface area are in a tank with a diameter of 60 feet and a height of 20 feet, we could start with the top and bottom.



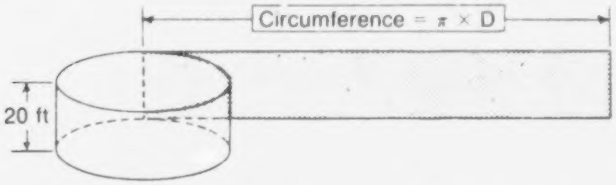
The area of the top and bottom ends are both $\pi \times R^2$

Area, sq ft $= 2$ ends $(\pi)(\text{Radius, ft})^2$

$= 2 \times \pi \times (30\ \text{ft})^2$

$= 5652$ sq ft

The surface area of the wall must now be calculated. If we made a vertical cut in the wall and unrolled it, the straightened wall would be the same length as the circumference of the floor and ceiling.



This length has been found to always be $\pi \times D$. In the case of the tank, the length of the wall would be:

Length, ft $= (\pi)\ (\text{Diameter, ft})$

$= 3.14 \times 60$ ft

$= 188.4$ ft

Area would be:

A_w sq ft $=$ Length, ft $\times$ Height, ft

$= 188.4\ \text{ft} \times 20\ \text{ft}$

$= 3768$ sq ft

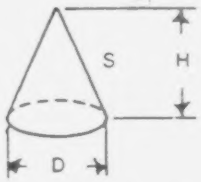
Outside Surface Area to Paint, sq ft $=$ Area of top and bottom, sq ft $+$ Area of wall, sq ft

$= 5652\ \text{sq ft} + 3768\ \text{sq ft}$

$= 9420$ sq ft

A container has inside and outside surfaces and you may need to paint both of them.

A.25 Cone



The lateral area of a cone is equal to ½ of the slant height (S) multiplied by the circumference of the base.

$$\boxed{A_L = \tfrac{1}{2} S \times \pi \times D = \pi \times S \times R}$$

In this case the slant height is not given, it may be calculated by:

$S = \sqrt{R^2 + H^2}$

Example: Find the entire outside area of a cone with a diameter of 30 inches and a height of 20 inches.

Slant Height, in $= \sqrt{(\text{Radius, in})^2 + (\text{Height, in})^2}$

$= \sqrt{(15\ \text{in})^2 + (20\ \text{in})^2}$

$= \sqrt{225\ \text{in}^2 + 400\ \text{in}^2}$

$= \sqrt{625\ \text{in}^2}$

$= 25$ in

Area of Cone, sq in $= \pi\ (\text{Slant Height, in})(\text{Radius, in})$

$= 3.14 \times 25\ \text{in} \times 15\ \text{in}$

$= 1177.5$ sq in

Since the entire area was asked for, the area of the base must be added.

Area, sq in $= 0.785\ (\text{Diameter, in})^2$

$= 0.785 \times 30\ \text{in} \times 30\ \text{in}$

$= 706.5$ sq in

$=$ Area of Cone, sq in $+$ Area of Bottom, sq in

Total Area, sq in $= 1177.5\ \text{sq. in} + 706.5\ \text{sq in}$

$= 1884$ sq in

A.26 Sphere

The surface area of a sphere or ball is equal to π multiplied by the diameter squared.

$$\boxed{A_S = \pi D^2}$$

If the radius is used, the formula becomes:

$A_S = \pi D^2 = \pi \times 2R \times 2R = 4\pi R^2$

Example: What is the surface area of a sphere-shaped water tank 20 feet in diameter?

Area, sq ft $= \pi\ (\text{Diameter, ft})^2$

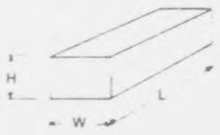
$= 3.14 \times 20\ \text{ft} \times 20\ \text{ft}$

$= 1256$ sq ft

A.3 VOLUMES

A.30 Rectangle

Volumes are measured in three dimensions or in cubic units. To calculate the volume of a rectangle, the area of the base is calculated in square units and then multiplied by the height. The formula then becomes:



$$\boxed{V = L \times W \times H}$$

Example: The length of a box is two feet, the width is 15 inches, and the height is 18 inches. Find its volume.

$$\text{Volume, cu ft} = \text{Length, ft} \times \text{Width, ft} \times \text{Height, ft}$$

$$= 2\ \text{ft} \times \frac{15\ \text{in}}{12\ \text{in/ft}} \times \frac{18\ \text{in}}{12\ \text{in/ft}}$$

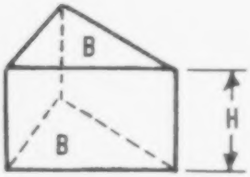
$$= 2\ \text{ft} \times 1.25\ \text{ft} \times 1.5\ \text{ft}$$

$$= 3.75\ \text{cu ft}$$

A.31 Prism

The same general rule that applies to the volume of a rectangle also applies to a prism.

$$\boxed{\text{Volume} = \text{Area of Base} \times \text{Height}}$$



Example: Find the volume of a prism with a base area of 10 square feet and a height of 5 feet. (Note that the base of a prism is triangular in shape)

$$\text{Volume, cu ft} = \text{Area of Base, sq ft} \times \text{Height, ft}$$

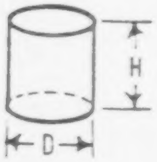
$$= 10\ \text{sq ft} \times 5\ \text{ft}$$

$$= 50\ \text{cu ft}$$

A.32 Cylinder

The volume of a cylinder is equal to the area of the base multiplied by the height.

$$\boxed{V = \pi R^2 \times H = 0.785\ D^2 \times H}$$



Example: A tank has a diameter of 100 feet and a depth of 12 feet. Find the volume.

$$\text{Volume, cu ft} = 0.785 \times (\text{Diameter, ft})^2 \times \text{Height, ft}$$

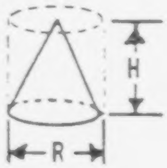
$$= 0.785 \times 100\ \text{ft} \times 100\ \text{ft} \times 12\ \text{ft}$$

$$= 94{,}200\ \text{cu ft}$$

A.33 Cone

The volume of a cone is equal to ⅓ the volume of a circular cylinder of the same height and diameter.

$$\boxed{V = \frac{\pi}{3} R^2 \times H}$$



Example: Calculate the additional volume in the cone portion of the tank in Section A.32 if the depth at the center of the tank is 16 ft. H = 16 ft − 12 ft.

$$\text{Volume, cu ft} = \frac{\pi}{3} \times (\text{Radius})^2 \times \text{Height, ft}$$

$$= \frac{\pi}{3} \times 50\ \text{ft} \times 50\ \text{ft} \times 4\ \text{ft}$$

$$= 10{,}500\ \text{cu ft}$$

A.34 Sphere

The volume of a sphere is equal to $\pi/6$ times the diameter cubed.

$$V = \frac{\pi}{6} \times D^3$$

Example: How much gas can be stored in a sphere with a diameter of 12 feet? (Assume atmospheric pressure.)

$$\text{Volume, cu ft} = \frac{\pi}{6} \times (\text{Diameter, ft})^3$$

$$= \frac{\pi}{6} \times \overset{2}{12}\ \text{ft} \times 12\ \text{ft} \times 12\ \text{ft}$$

$$= 904.32\ \text{cubic feet}$$

A.4 METRIC SYSTEM

The two most common systems of weights and measures are the English system and the Metric system. Of these two, the Metric system is more popular with most of the nations of the world. The reason for this is that the Metric system is based on a system of tens and is therefore easier to remember and easier to use than the English system. Even though the basic system in the United States is the English system, the scientific community uses the Metric system almost exclusively. Many organizations have urged, for good reason, that the United States switch to the Metric system. Today the Metric system is gradually becoming the standard system of measurement in the United States.

As the United States changes from the English to the Metric system, some confusion and controversy has developed. For example, which is the correct spelling of the following words:

1. Liter or litre?
2. Meter or metre?

The U.S. National Bureau of Standards, the Water Pollution Control Federation, and the American Water Works Association use litre and metre. The U.S. Government uses liter and meter and accepts no deviations. Some people argue that METRE should be used to measure LENGTH and that METER should be used to measure FLOW RATES (like a water or electric meter). Liter and Meter are used in this manual because this is most consistent with spelling in the United States.

One of the most frequent arguments heard against the U.S. switching to the Metric system was that the costs of switching manufacturing processes would be excessive. Pipe manufacturers have agreed upon the use of a "soft" metric conversion system during the conversion to the Metric system. Past practice in the U.S. has identified some types of pipe by external (outside) diameter while other types are classified by nominal (existing only in name, not real or actual) bore. This means that a six-inch pipe does not have a six-inch inside diameter. With the strict or "hard" metric system, a six-inch pipe would be a 152.4 mm (6 in × 25.4 mm/in) pipe. In the "soft" metric system a six-inch pipe is a 150 mm (6 in × 25 mm/in) pipe. Typical customary and "soft" metric pipe-size designations are shown below:

PIPE-SIZE DESIGNATIONS

Customary, in	2	4	6	8	10	12	15	18
"Soft" Metric, mm	50	100	150	200	250	300	375	450
Customary, in	24	30	36	42	48	60	72	84
"Soft" Metric, mm	600	750	900	1050	1200	1500	1800	2100

In order to study the Metric system, you must know the meanings of the terminology used. Following is a list of Greek and Latin prefixes used in the Metric system.

PREFIXES USED IN THE METRIC SYSTEM

Prefixes	Symbol	Meaning
Micro	μ	1/1 000 000 or 0.000 001
Milli	m	1/1000 or 0.001
Centi	c	1/100 or 0.01
Deci	d	1/10 or 0.1
Unit		1
Deka	da	10
Hecto	h	100
Kilo	k	1000
Mega	M	1 000 000

A.40 Measures of Length

The basic measure of length is the meter.

1 kilometer (km) = 1000 meters (m)
1 meter (m) = 100 centimeters (cm)
1 centimeter (cm) = 10 millimeters (mm)

Kilometers are usually used in place of miles, meters are used in place of feet and yards, centimeters are used in place of inches and millimeters are used for inches and fractions of an inch

LENGTH EQUIVALENTS

1 kilometer	= 0.621 mile	1 mile	= 1.61 kilometers
1 meter	= 3.28 feet	1 foot	= 0.305 meter
1 meter	= 39.37 inches	1 inch	= 0.0254 meter
1 centimeter	= 0.3937 inch	1 inch	= 2.54 centimeter
1 millimeter	= 0.0394 inch	1 inch	= 25.4 millimeters

NOTE: The above equivalents are reciprocals. If one equivalent is given, the reverse can be obtained by division. For instance, if one meter equals 3.28 feet, one foot equals 1/3.28 meter, or 0.305 meter.

A.41 Measures of Capacity or Volume

The basic measure of capacity in the Metric system is the liter. For measurement of large quantities the cubic meter is sometimes used.

1 kiloliter (k*L*) = 1000 liters (*L*) = 1 cu meter (m^3)

1 liter (*L*) = 1000 milliliters (m*L*)

Kiloliters, or cubic meters, are used to measure capacity of large storage tanks or reservoirs in place of cubic feet or gallons. Liters are used in place of gallons or quarts. Milliliters are used in place of quarts, pints, or ounces.

CAPACITY EQUIVALENTS

1 kiloliter	= 264.2 gallons	1 gallon	= 0.003785 kiloliter
1 liter	= 1.057 quarts	1 quart	= 0.946 liter
1 liter	= 0.2642 gallons	1 gallon	= 3.785 liters
1 milliliter	= 0.0353 ounce	1 ounce	= 28.35 milliliters

A.42 Measures of Weight

The basic unit of weight in the Metric system is the gram. One cubic centimeter of water at maximum density weighs one gram, and thus there is a direct, simple relation between volume of water and weight in the Metric system.

1 kilogram (kg) = 1000 grams (gm)
1 gram (gm) = 1000 milligrams (mg)
1 milligram (mg) = 1000 micrograms (μg)

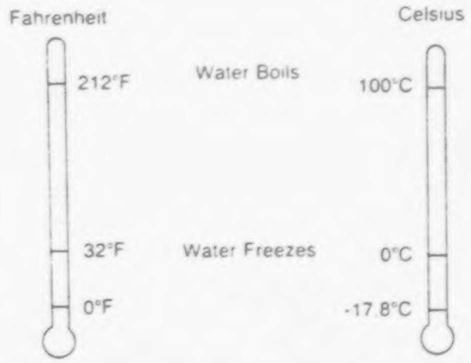
Grams are usually used in place of ounces, and kilograms are used in place of pounds.

WEIGHT EQUIVALENTS

1 kilogram	= 2.205 pounds	1 pound	= 0.4536 kilogram
1 gram	= 0.0022 pound	1 pound	= 453.6 grams
1 gram	= 0.0353 ounce	1 ounce	= 28.35 grams
1 gram	= 15.43 grains	1 grain	= 0.0648 gram

A.43 Temperature

Just as the operator should become familiar with the Metric system, you should also become familiar with the centigrade (Celsius) scale for measuring temperature. There is nothing magical about the centigrade scale — it is simply a different size than the Fahrenheit scale. The two scales compare as follows:



The two scales are related in the following manner:

$$\boxed{\begin{array}{ll}\text{Fahrenheit} = (^\circ C \times 9/5) + 32^\circ \\ \text{Celsius} \quad = (^\circ F - 32^\circ) \times 5/9\end{array}}$$

Example: Convert 20° Celsius to Fahrenheit.

$$F = (^\circ C \times 9/5) + 32^\circ$$
$$F = (20^\circ \times 9/5) + 32^\circ$$
$$F = \frac{180^\circ}{5} + 32^\circ$$
$$= 36^\circ + 32^\circ$$
$$= 68^\circ F$$

Example: Convert −10°C to °F.

$$F = (-10^\circ \times 9/5) + 32^\circ$$
$$F = -90^\circ/5 + 32^\circ$$
$$= -18^\circ + 32^\circ$$
$$= 14^\circ F$$

Example: Convert −13°F to °C.

$$C = (°F - 32°) \times \frac{5}{9}$$

$$C = (-13° - 32°) \times \frac{5}{9}$$

$$= -45° \times \frac{5}{9}$$

$$= -5° \times 5$$

$$= -25°C$$

A.44 Milligrams per Liter

Milligrams per liter (mg/*L*) is a unit of measurement used in laboratory and scientific work to indicate very small concentrations of dilutions. Since water contains small concentrations of dissolved substances and solids, and since small amounts of chemical compounds are sometimes used in water treatment processes, the term milligrams per liter is also common in treatment plants. It is a weight/volume relationship.

As previously discussed:

1000 liters = 1 cubic meter = 1,000,000 cubic centimeters

Therefore

1 liter = 1000 cubic centimeters

Since one cubic centimeter of water weighs one gram.

1 liter of water = 1000 grams or 1,000,000 milligrams

$$\boxed{\frac{1 \text{ milligram}}{\text{liter}} = \frac{1 \text{ milligram}}{1{,}000{,}000 \text{ milligrams}} = \frac{1 \text{ part}}{\text{million parts}} = \text{1 part per million (ppm)}}$$

Milligrams per liter and parts per million (parts) may be used interchangeably as long as the liquid density is 1.0 gm/cu cm or 62.43 lb/cu ft. A concentration of 1 milligram/liter (mg/*L*) or 1 ppm means that there is 1 part of substance by weight for every 1 million parts of water. A concentration of 10 mg/*L* would mean 10 parts of substance per million parts of water.

To get an idea of how small 1 mg/*L* is, divide the numerator and denominator of the fraction by 10,000. This, of course, does not change its value since, 10,000 ÷ 10,000 is equal to one.

$$\boxed{1\frac{\text{mg}}{L} = \frac{1 \text{ mg}}{1{,}000{,}000 \text{ mg}} = \frac{1/10{,}000 \text{ mg}}{1{,}000{,}000/10{,}000 \text{ mg}} = \frac{0.0001 \text{ mg}}{100 \text{ mg}} = 0.0001\%}$$

Therefore, 1 mg/*L* is equal to one ten-thousandth of a percent, or

1% is equal to 10,000 mg/*L*

To convert mg/*L* to %, move the decimal point four places or numbers to the left.

Working problems using milligrams per liter or parts per million is a part of everyday operation in most water treatment plants.

A.45 Example Problems

Example: Raw water flowing into a plant at a rate of five million pounds per day is prechlorinated at 5 mg/*L*. How many pounds of chlorine are used per day?

$$5 \text{ mg}/L = \frac{5 \text{ lbs chlorine}}{\text{million lbs water}}$$

$$\text{Chlorine Feed, lbs/day} = \text{Concentration, lbs/M lbs} \times \text{Flow, lbs/day}$$

$$= \frac{5 \text{ lbs}}{\cancel{\text{million lbs}}} \times \frac{5 \cancel{\text{ million lbs}}}{\text{day}}$$

$$= 25 \text{ lbs/day}$$

There is one thing that is unusual about the above problem and that is the flow is reported in pounds per day. In most treatment plants, flow is reported in terms of gallons per minute or gallons per day. To convert these flow figures to weight, an additional conversion factor is needed. One gallon of water weighs 8.34 pounds. Using this factor, it is possible to convert flow in gallons per day to flow in pounds per day.

Example: A well pump with a flow of 3.5 million gallons per day (MGD) chlorinates the water with 2.0 mg/*L* chlorine. How many pounds of chlorine are used per day?

$$\text{Flow, lbs/day} = \text{Flow, } \frac{\text{M gal}}{\text{day}} \times 8.34 \frac{\text{lb}}{\text{gal}}$$

$$= \frac{3.5 \text{ million } \cancel{\text{gal}}}{\text{day}} \times \frac{8.34 \text{ lbs}}{\cancel{\text{gal}}}$$

$$= 29.19 \text{ million lbs/day}$$

$$\text{Chlorine Feed, lbs/day} = \text{Level, mg}/L \times \text{Flow, M lb/day}$$

$$= \frac{2.0 \cancel{\text{ mg}}^{*}}{\cancel{\text{million mg}}} \times \frac{29.10 \cancel{\text{ million}} \text{ lbs}}{\text{day}}$$

$$= 58.38 \text{ lbs/day}$$

In solving the above problem, a relation was used that is most important to understand and commit to memory.

$$\boxed{\text{Feed, lbs/day} = \text{Flow, MGD} \times \text{Dose, mg}/L \times 8.34 \text{ lbs/gal}}$$

Example: A chlorinator is set to feed 50 pounds of chlorine per day to a flow of 0.8 MGD. What is the chlorine dose in mg/*L*?

$$\text{Conc. or Dose, mg}/L = \frac{\text{lbs/day}}{\text{MGD} \times 8.34 \text{ lb/gal}}$$

$$= \frac{50 \text{ lb/day}}{0.80 \text{ MG/day} \times 8.34 \text{ lb/gal}}$$

$$= \frac{50 \text{ lb}}{6.672 \text{ M lb}}$$

$$= 7.5 \text{ mg}/L, \text{ or } 7.5 \text{ ppm}$$

Example: A pump delivers 500 gallons per minute to a water treatment plant. Alum is added at 10 mg/*L*. How much alum is used in pounds per day?

---

* Remember that $\frac{1 \text{ mg}}{\text{M mg}} = \frac{1 \text{ lb}}{\text{M lb}}$ They are identical ratios.

Flow, MGD = Flow, GPM × 60 min/hr × 24 hr/day

$$= \frac{500\ \text{gal}}{\cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{\cancel{\text{hr}}} \times \frac{24\ \cancel{\text{hr}}}{\text{day}}$$

= 720,000 gal/day

= 0.72 MGD

Alum Feed, lbs/day = Flow, MGD × Dose, mg/L × 8.34 lbs/gal

$$= \frac{0.72\ \cancel{\text{M}}\ \cancel{\text{gal}}}{\text{day}} \times \frac{10\ \cancel{\text{mg}}}{\cancel{\text{M}}\ \cancel{\text{mg}}} \times \frac{8.34\ \text{lb}}{\cancel{\text{gal}}}$$

= 60.048 lbs/day or about 60 lbs/day

A.5 WEIGHT-VOLUME RELATIONS

Another factor for the operator to remember, in addition to the weight of a gallon of water, is the weight of a cubic foot of water. One cubic foot of water weighs 62.4 lbs. If these two weights are divided, it is possible to determine the number of gallons in a cubic foot.

$$\frac{62.4\ \cancel{\text{pounds}}/\text{cu ft}}{8.34\ \cancel{\text{pounds}}/\text{gal}} = 7.48\ \text{gal/cu ft}$$

Thus we have another very important relationship to commit to memory.

$$\boxed{8.34\ \text{lb/gal} \times 7.48\ \text{gal/cu ft} = 62.4\ \text{lb/cu ft}}$$

It is only necessary to remember two of the above items since the third may be found by calculation. For most problems, 8⅓ lbs/gal and 7½ gal/cu ft will provide sufficient accuracy.

Example: Change 1000 cu ft of water to gallons.

1000 cu ft × 7.48 gal/cu ft = 7480 gallons

Example: What is the weight of three cubic feet of water?

62.4 lb/cu ft × 3 cu ft = 187.2 lbs

Example: The net weight of a tank of water is 750 lbs. How many gallons does it contain?

$$\frac{750\ \cancel{\text{lb}}}{8.34\ \cancel{\text{lb}}/\text{gal}} = 90\ \text{gals}$$

A.6 FORCE, PRESSURE, AND HEAD

In order to study the forces and pressures involved in fluid flow, it is first necessary to define the terms used.

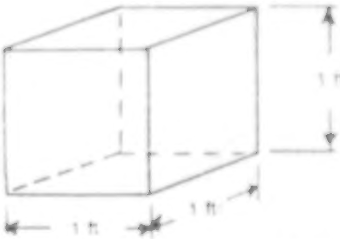
FORCE: The push exerted by water on any surface being used to confine it. Force is usually expressed in pounds, tons, grams, or kilograms.

PRESSURE: The force per unit area. Pressure can be expressed in many ways, but the most common term is pounds per square inch (psi).

HEAD: Vertical distance from the water surface to a reference point below the surface. Usually expressed in feet or meters.

An *EXAMPLE* should serve to illustrate these terms.

If water were poured into a one-foot cubical container, the *FORCE* acting on the bottom of the container would be 62.4 pounds.



The *PRESSURE* acting on the bottom would be 62.4 pounds per square foot. The area of the bottom is also 12 in × 12 in = 144 in². Therefore, the pressure may also be expressed as:

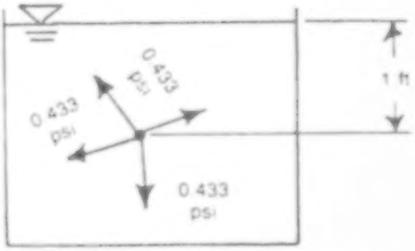
$$\text{Pressure, psi} = \frac{62.4\ \text{lb}}{\text{sq ft}} = \frac{62.4\ \text{lb/sq ft}}{144\ \text{sq in/sq ft}}$$

= 0.433 lb/sq in

= 0.433 psi

Since the height of the container is one foot, the *HEAD* would be one foot.

The pressure in any vessel at one foot of depth or one foot of head is 0.433 psi acting in any direction.



If the depth of water in the previous example were increased to two feet, the pressure would be:

$$p = \frac{2\ (62.4\ \text{lb})}{144\ \text{sq in}} = \frac{124.8\ \text{lb}}{144\ \text{sq in}} = 0.866\ \text{psi}$$

Therefore we can see that for every foot of head, the pressure increases by 0.433 psi. Thus, the general formula for pressure becomes:

$$\boxed{\text{p, psi} = 0.433\ (\text{H, ft})}$$

H = feet of head

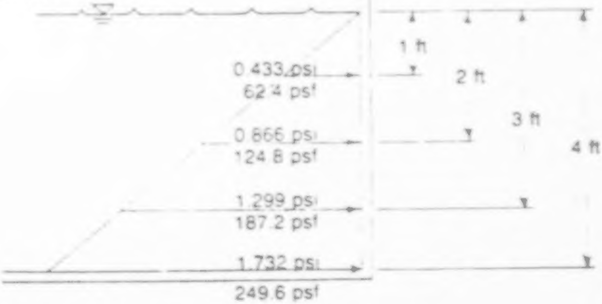
p = pounds per square *INCH* of pressure

$$\boxed{\text{P, lb/sq ft} = 62.4\ (\text{H, ft})}$$

H = feet of head

P = pounds per square *FOOT* of pressure

We can now draw a diagram of the pressure acting on the side of a tank. Assume a four-foot deep tank. The pressures shown on the tank are gage pressures. These pressures do not include the atmospheric pressure acting on the surface of the water.



$p_0 = 0.433 \times 0 = 0.0$ psi
$p_1 = 0.433 \times 1 = 0.433$ psi
$p_2 = 0.433 \times 2 = 0.866$ psi
$p_3 = 0.433 \times 3 = 1.299$ psi
$p_4 = 0.433 \times 4 = 1.732$ psi

$P_0 = 62.4 \times 0 = 0.0$ lb/sq ft
$P_1 = 62.4 \times 1 = 62.4$ lb/sq ft
$P_2 = 62.4 \times 2 = 124.8$ lb/sq ft
$P_3 = 62.4 \times 3 = 187.2$ lb/sq ft
$P_4 = 62.4 \times 4 = 249.6$ lb/sq ft

The average *PRESSURE* acting on the tank wall is 1.732 psi/2 = 0.866 psi, or 249.2 psf/2 = 124.8 psf. We divided by two to obtain the average pressure because there is zero pressure at the top and 1.732 psi pressure on the bottom of the wall.

If the wall were five feet long, the pressure would be acting over the entire 20 square foot (5 ft × 4 ft) area of the wall. The total force acting to push the wall would be:

Force, lb = (Pressure, lb/sq ft)(Area, sq ft)
= 124.8 lb/sq ft × 20 sq ft
= 2496 lbs

If the pressure in psi were used, the problem would be similar:

Force, lb = (Pressure, lb/sq in)(Area, sq in)
= 0.866 psi × 48 in × 60 in
= 2494 lb*

---

* Difference in answer due to rounding off of decimal points.

The general formula, then, for finding the total force acting on a side wall of a tank is:

$\boxed{F = 31.2 \times H^2 \times L}$

F = force in pounds
H = head in feet
L = length of wall in feet
31.2 = constant with units of lbs/cu ft and considers the fact that the force results from H/2 or half the depth of the water which is the average depth. The force is exerted at H/3 from the bottom.

Example: Find the force acting on a five-foot long wall in a four-foot deep tank.

Force, lb = 31.2 (Head, ft)^2 (Length, ft)
= 31.2 lb/cu ft × (4 ft)^2 × 5 ft
= 2496 lbs

Occasionally an operator is warned: *NEVER EMPTY A TANK DURING PERIODS OF HIGH GROUNDWATER.* Why? The pressure on the bottom of the tank caused by the water surrounding the tank will tend to float the tank like a cork if the upward force of the water is greater than the weight of the tank.

$\boxed{F = 62.4 \times H \times A}$

F = upward force in pounds
H = head of water on tank bottom in feet
A = area of bottom of tank in square feet
62.4 = a constant with units of lbs/cu ft

This formula is approximately true if the tank doesn't crack, leak, or start to float.

Example: Find the upward force on the bottom of an empty tank caused by a groundwater depth of 8 feet above the tank bottom. The tank is 20 ft wide and 40 ft long.

Force, lb = 62.4 (Head, ft)(Area, sq ft)
= 62.4 lb/cu ft × 8 ft × 20 ft × 40 ft
= 399,400 lb

A.7 VELOCITY AND FLOW RATE

A.70 Velocity

The velocity of a particle or substance is the speed at which it is moving. It is expressed by indicating the length of travel and how long it takes to cover the distance. Velocity can be expressed in almost any distance and time units. For instance, a car may be traveling at a rate of 280 miles per five hours. However, it is normal to express the distance traveled per unit time. The above example would then become:

$$\text{Velocity, mi/hr} = \frac{280 \text{ miles}}{5 \text{ hours}}$$
$$= 56 \text{ miles/hour}$$

The velocity of water in a channel, pipe, or other conduit can be expressed in the same way. If the particle of water travels 600 feet in five minutes, the velocity is:

$$\text{Velocity, ft/min} = \frac{\text{distance, ft}}{\text{time, minutes}}$$
$$= \frac{600 \text{ ft}}{5 \text{ min}}$$
$$= 120 \text{ ft/min}$$

If you wish to express the velocity in feet per second, multiply by 1 min/60 seconds.

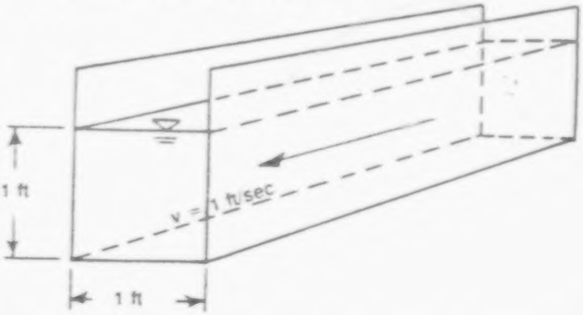
NOTE: $\frac{1 \text{ minute}}{60 \text{ seconds}}$ is like $\frac{1}{1}$ and does not change the relative value of the answer. It only changes the form of the answer.

Velocity, ft/sec = (Velocity, ft/min)(1 min/60 sec)

$$= \frac{120 \text{ ft}}{\cancel{\text{min}}} \times \frac{1 \cancel{\text{min}}}{60 \text{ sec}}$$
$$= \frac{120 \text{ ft}}{60 \text{ sec}}$$
$$= 2 \text{ ft/sec}$$

A.71 Flow Rate

If water in a one-foot wide channel is one foot deep, then the cross sectional area of the channel is 1 ft × 1 ft = 1 sq ft.



If the velocity in this channel is 1 ft per second, then each second a body of water 1 sq ft in area and 1 ft long will pass a given point. The volume of this body of water would be 1 cubic foot. Since one cubic foot of water would pass by every second, the flow rate would be equal to 1 cubic foot per second, or 1 cfs.

To obtain the flow rate in the above example the velocity was multiplied by the cross sectional area. This is another important general formula.

$\boxed{Q = V \times A}$

Q = flow rate, cfs or cu ft/sec

V = velocity, ft/sec

A = area, sq ft

Example: A rectangular channel 3 feet wide contains water 2 feet deep and flowing at a velocity of 1.5 feet per second. What is the flow rate in cfs?

$$Q = V \times A$$

$$\begin{aligned}\text{Flow rate, cfs} &= \text{Velocity, ft/sec} \times \text{Area, sq ft}\\ &= 1.5\ \text{ft/sec} \times 3\ \text{ft} \times 2\ \text{ft}\\ &= 9\ \text{cu ft/sec}\end{aligned}$$

Example: Flow in a 2.5 foot wide channel is 1.4 ft deep and measures 11.2 cfs. What is the average velocity?

In this problem we want to find the velocity. Therefore, we must rearrange the general formula to solve for velocity.

$$V = \frac{Q}{A}$$

$$\begin{aligned}\text{Velocity, ft/sec} &= \frac{\text{Flow Rate, cu ft/sec}}{\text{Area, sq ft}}\\ &= \frac{11.2\ \text{cu ft/sec}}{2.5\ \text{ft} \times 1.4\ \text{ft}}\\ &= \frac{11.2\ \text{ft/sec}}{3.5}\\ &= 3.2\ \text{ft/sec}\end{aligned}$$

Example: Flow in an 8-inch pipe is 500 GPM. What is the average velocity?

$$\begin{aligned}\text{Area, sq ft} &= 0.785\ (\text{Diameter, ft})^2\\ &= 0.785\ (8/12\ \text{ft})^2\\ &= 0.785\ (2/3\ \text{ft})^2\\ &= 0.785\ (2/3\ \text{ft})(2/3\ \text{ft})\\ &= 0.785\ (4/9\ \text{ft}^2)\\ &= 0.35\ \text{sq ft}\end{aligned}$$

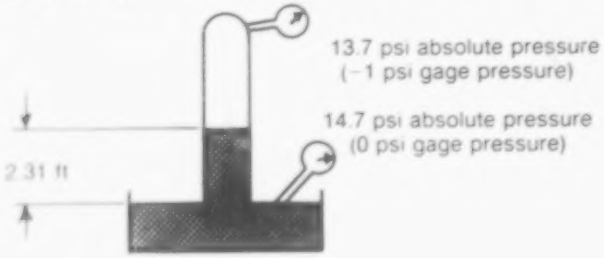
$$\begin{aligned}\text{Flow, cfs} &= \text{Flow, gal/min} \times \frac{\text{cu ft}}{7.48\ \text{gal}} \times \frac{1\ \text{min}}{60\ \text{sec}}\\ &= \frac{500\ \text{gal}}{\text{min}} \times \frac{\text{cu ft}}{7.48\ \text{gal}} \times \frac{1\ \text{min}}{60\ \text{sec}}\\ &= \frac{500\ \text{cu ft}}{448.8\ \text{sec}}\\ &= 1.114\ \text{cfs}\end{aligned}$$

$$\begin{aligned}\text{Velocity, ft/sec} &= \frac{\text{Flow, cu ft/sec}}{\text{Area, sq ft}}\\ &= \frac{1.114\ \text{ft}^3/\text{sec}}{0.35\ \text{ft}^2}\\ &= 3.18\ \text{ft/sec}\end{aligned}$$

A.8 PUMPS

A.80 Pressure

Atmospheric pressure at sea level is approximately 14.7 psi. This pressure acts in all directions and on all objects. If a tube is placed upside down in a basin of water and a 1 psi partial vacuum is drawn on the tube, the water in the tube will rise 2.31 feet.



NOTE: 1 ft of water = 0.433 psi, therefore,

$$1\ \text{psi} = \frac{1}{0.433}\ \text{ft} = 2.31\ \text{ft of water}$$

The action of the partial vacuum is what gets water out of a sump or well and up to a pump. It is not sucked up, but it is pushed up by atmospheric pressure on the water surface in the sump. If a complete vacuum could be drawn, the water would rise 2.31 × 14.7 = 33.9 feet, but this is impossible to achieve. The practical limit of the suction lift of a positive displacement pump is about 22 feet, and that of a centrifugal pump is 15 feet.

A.81 Work

Work can be expressed as lifting a weight a certain vertical distance. It is usually defined in terms of foot-pounds.

Example: A 165-pound man runs up a flight of stairs 20 feet high. How much work did he do?

$$\begin{aligned}\text{Work, ft-lb} &= \text{Weight, lb} \times \text{Height, ft}\\ &= 165\ \text{lb} \times 20\ \text{ft}\\ &= 3300\ \text{ft-lb}\end{aligned}$$

A.82 Power

Power is a rate of doing work and is usually expressed in foot-pounds per minute.

Example: If the man in the above example runs up the stairs in three seconds, how much power has he exerted?

$$\begin{aligned}\text{Power, ft-lbs/sec} &= \frac{\text{Work, ft-lb}}{\text{Time, sec}}\\ &= \frac{3300\ \text{ft-lbs}}{3\ \cancel{\text{sec}}} \times \frac{60\ \cancel{\text{sec}}}{\text{minute}}\\ &= 66{,}000\ \text{ft-lb/min}\end{aligned}$$

A.83 Horsepower

Horsepower is also a unit of power. One horsepower is defined as 33,000 ft-lbs per minute or 746 watts.

Example: How much horsepower has the man in the previous example exerted as he climbs the stairs?

$$\text{Horsepower, HP} = (\text{Power, ft-lb/min})\left(\frac{\text{HP}}{33{,}000\text{ ft-lb/min}}\right)$$

$$= 66{,}000\text{ ft-lb/min} \times \frac{\text{Horsepower}}{33{,}000\text{ ft-lb/min}}$$

$$= 2\text{ HP}$$

Work is also done by lifting water. If the flow from a pump is converted to a weight of water and multiplied by the vertical distance it is lifted, the amount of work or power can be obtained.

$$\text{Horsepower, HP} = \frac{\text{Flow, gal}}{\text{min}} \times \text{Lift, ft} \times \frac{8.34\text{ lb}}{\text{gal}} \times \frac{\text{Horsepower}}{33{,}000\text{ ft-lb/min}}$$

Solving the above relation, the amount of horsepower necessary to lift the water is obtained. This is called water horsepower.

$$\text{Water, HP} = \frac{(\text{Flow, GPM})(\text{H, ft})}{3960^{*}}$$

$$^{*}\ \frac{8.34\text{ lb}}{\text{gal}} \times \frac{\text{HP}}{33{,}000\text{ ft-lb/min}} = \frac{1}{3960}$$

1 gallon weighs 8.34 pounds and 1 horsepower is the same as 33,000 ft-lb/min.

H or Head in feet is the same as Lift in feet.

However, since pumps are not 100% efficient (they cannot transmit all the power put into them), the horsepower supplied to a pump is greater than the water horsepower. Horsepower supplied to the pump is called brake horsepower.

$$\boxed{\text{Brake, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p}}$$

E_p = Efficiency of Pump (Usual range 50-85%, depending on type and size of pump)

Motors are also not 100% efficient; therefore, the power supplied to the motor is greater than the motor transmits.

$$\boxed{\text{Motor, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p \times E_m}}$$

E_m = Efficiency of motor (Usual range 80-95%, depending on type and size of motor)

The above formulas have been developed for the pumping of water and wastewater which have a specific gravity of 1.0. If other liquids are to be pumped, the formulas must be multiplied by the specific gravity of the liquid.

Example: A flow of 500 GPM of water is to be pumped against a total head of 100 feet by a pump with an efficiency of 70%. What is the pump horsepower?

$$\text{Brake, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p}$$

$$= \frac{500 \times 100}{3960 \times 0.70}$$

$$= 18\text{ HP}$$

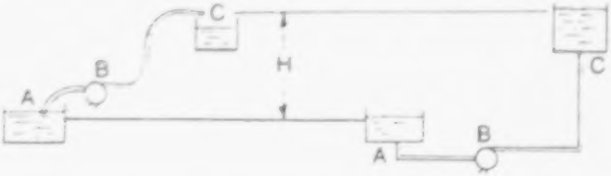
Example: Find the horsepower required to pump gasoline (specific gravity = 0.75) in the above problem.

$$\text{Brake, HP} = \frac{500 \times 100 \times 0.75}{3960 \times 0.70}$$

$$= 13.5\text{ HP}$$ (gasoline is lighter and requires less horsepower)

A.84 Head

Basically, the head that a pump must work against is determined by measuring the vertical distance between the two water surfaces, or the distance the water must be lifted. This is called the static head. Two typical conditions for lifting water are shown below.



If a pump were designed in the above examples to pump only against head H, the water would never reach the intended point. The reason for this is that the water encounters friction in the pipelines. Friction depends on the roughness and length of pipe, the pipe diameter, and the flow velocity. The turbulence caused at the pipe entrance (point A); the pump (point B); the pipe exit (point C); and at each elbow, bend, or transition also adds to these friction losses. Tables and charts are available in Section A.88 for calculation of these friction losses so they may be added to the measured or static head to obtain the total head. For short runs of pipe which do not have high velocities, the friction losses are generally less than 10 percent of the static head.

Example: A pump is to be located eight feet above a wet well and must lift 1.8 MGD another 50 feet to a storage reservoir. If the pump has an efficiency of 75% and the motor an efficiency of 90%, what is the cost of the power consumed if one kilowatt hour costs 4 cents?

Since we are not given the length or size of pipe and the number of elbows or bends, we will assume friction to be 10% of static head.

$$\text{Static Head, ft} = \text{Suction Lift, ft} + \text{Discharge Head, ft}$$

$$= 8\text{ ft} + 50\text{ ft}$$

$$= 58\text{ ft}$$

$$\text{Friction Losses, ft} = 0.1\ (\text{Static Head, ft})$$

$$= 0.1\ (58\text{ ft})$$

$$= 5.8\text{ ft}$$

$$\text{Total Dynamic Head, ft} = \text{Static Head, ft} + \text{Friction Losses, ft}$$

$$= 58\text{ ft} + 5.8\text{ ft}$$

$$= 63.8\text{ ft}$$

$$\text{Flow, GPM} = \frac{1{,}800{,}000\text{ gal}}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{24\ \cancel{\text{hr}}} \times \frac{1\ \cancel{\text{hr}}}{60\text{ min}}$$

$$= 1250\text{ GPM}$$ (assuming pump runs 24 hours per day)

$$\text{Motor, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p \times E_m}$$

$$= \frac{1250 \times 63.8}{3960 \times 0.75 \times 0.9}$$

$$= 30 \text{ HP}$$

$$\text{Kilowatt-hrs} = 30 \cancel{\text{HP}} \times 24 \text{ hrs/day} \times 0.746 \text{ kw/}\cancel{\text{HP}}^{*}$$

$$= 537 \text{ kilowatt-hrs/day}$$

$$\text{Cost} = \text{KWH} \times \$0.04/\text{KWH}$$

$$= 537 \times 0.04$$

$$= \$21.48/\text{day}$$

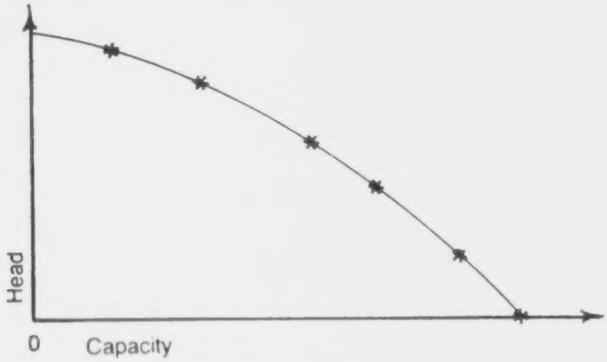
---

* See Conversion Tables — Section A.10, "Power."

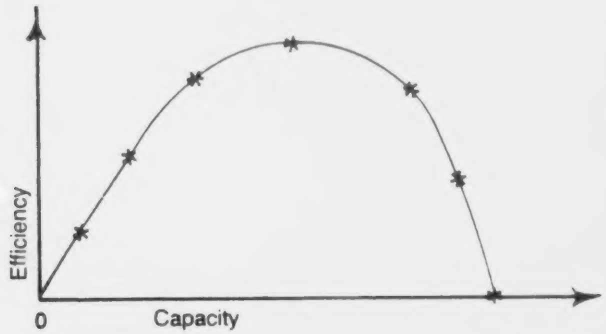
A.85 Pump Characteristics

The discharge of a centrifugal pump, unlike a positive displacement pump, can be made to vary from zero to a maximum capacity which depends on the speed, head, power, and specific impeller design. The interrelation of capacity, efficiency, head, and power is known as the characteristics of the pump.

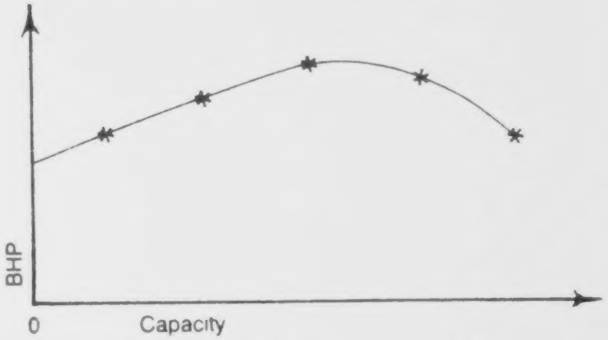
The first relation normally looked at when searching for a pump is the head vs. capacity. The head of a centrifugal pump normally rises as the capacity is reduced. If the values are plotted on a graph they appear as follows:



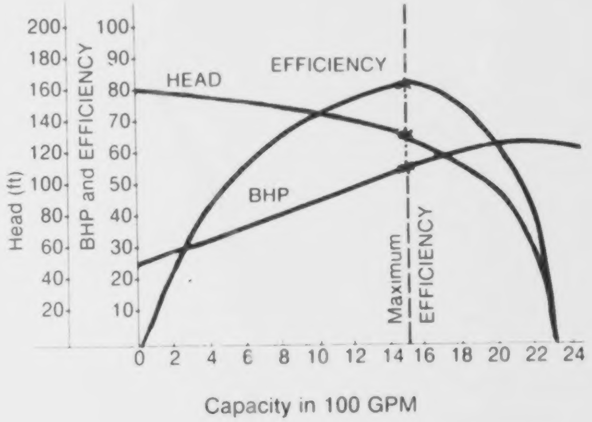
Another important characteristic is the pump efficiency. It begins from zero at no discharge, increases to a maximum, and then drops as the capacity is increased. Following is a graph of efficiency vs. capacity:



The last important characteristic is the brake horsepower or the power input to the pump. The brake horsepower usually increases with increasing capacity until it reaches a maximum, then it normally reduces slightly.



These pump characteristic curves are quite important. Pump sizes are normally picked from these curves rather than calculations. For ease of reading, the three characteristic curves are normally plotted together. A typical graph of pump characteristics is shown as follows:



The curves show that the maximum efficiency for the particular pump in question occurs at approximately 1475 GPM, a head of 132 feet, and a brake horsepower of 58. Operating at this point the pump has an efficiency of approximately 85%. This can be verified by calculation:

$$\text{BHP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E}$$

As previously explained, a number can be written over one without changing its value:

$$\frac{\text{BHP}}{1} = \frac{\text{GPM} \times \text{H}}{3960 \times \text{E}}$$

Since the formula is now in ratio form, it can be cross multiplied.

$$\text{BHP} \times 3960 \times \text{E} = \text{GPM} \times \text{H} \times 1$$

Solving for E,

$$\text{E} = \frac{\text{GPM} \times \text{H}}{3960 \times \text{BHP}}$$

$$\text{E} = \frac{1475 \text{ GPM} \times 132 \text{ ft}}{3960 \times 58 \text{ HP}}$$

$$= 0.85 \text{ or } 85\% \text{ (Check)}$$

The preceding is only a brief description of pumps to familiarize the operator with their characteristics. The operator does not normally specify the type and size of pump needed at a plant. If a pump is needed, the operator should be able to supply the information necessary for a pump supplier to provide the best possible pump for the lowest cost. Some of the information needed includes:

1. Flow range desired
2. Head conditions
   a. Suction head or lift
   b. Pipe and fitting friction head
   c. Discharge head
3. Type of fluid pumped and temperature
4. Pump location

A.86 Evaluation of Pump Performance

1. Capacity

Sometimes it is necessary to determine the capacity of a pump. This can be accomplished by determining the time it takes a pump to fill or empty a portion of a wet well or diversion box when all inflow is blocked off.

EXAMPLE:

a. Measure the size of the wet well.

Length = 10 ft
Width = 10 ft
Depth = 5 ft (We will measure the time it takes to lower the well a distance of five feet)

$$\text{Volume, cu ft} = \text{L, ft} \times \text{W, ft} \times \text{D, ft}$$
$$= 10\text{ ft} \times 10\text{ ft} \times 5\text{ ft}$$
$$= 500\text{ cu ft}$$

b. Record time for water to drop five feet in wet well.

Time = 10 minutes 30 seconds
= 10.5 minutes

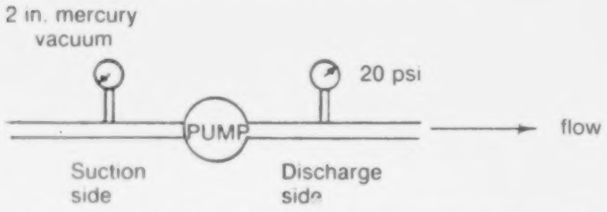
c. Calculate pumping rate or capacity.

$$\text{Pumping Rate, GPM} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$
$$= \frac{(500\text{ cu ft})(7.5\text{ gal/cu ft})}{10.5\text{ min}}$$
$$= \frac{3750}{10.5}$$
$$= 357\text{ GPM}$$

If you know the total dynamic head and have the pump's performance curves, you can determine if the pump is delivering at design capacity. If not, try to determine the cause (see Chapter 18, "Maintenance"). After a pump overhaul, the pump's actual performance (flow, head, power and efficiency) should be compared with the pump manufacturer's performance curves. This procedure for calculating the rate of filling or emptying of a wet well or diversion box can be used to calibrate flow meters.

2. Efficiency

To estimate the efficiency of the pump in the previous example, the total head must be known. This head may be estimated by measuring the suction and discharge pressure. Assume these were measured as follows:



No additional information is necessary if we assume the pressure gages are at the same height and the pipe diameters are the same. Both pressure readings must be converted to feet.

$$\text{Suction Lift, ft} = 2\text{ in Mercury} \times \frac{1.133\text{ ft water}^*}{1\text{ in Mercury}}$$
$$= 2.27\text{ ft}$$
$$\text{Discharge Head, ft} = 20\text{ psi} \times 2.31\text{ ft/psi}^*$$
$$= 46.20\text{ ft}$$
$$\text{Total Head, ft} = \text{Suction Lift, ft} + \text{Discharge Head, ft}$$
$$= 2.27\text{ ft} + 46.20\text{ ft}$$
$$= 48.47\text{ ft}$$

---

*See Conversion Tables — Section A.10, "Pressure."

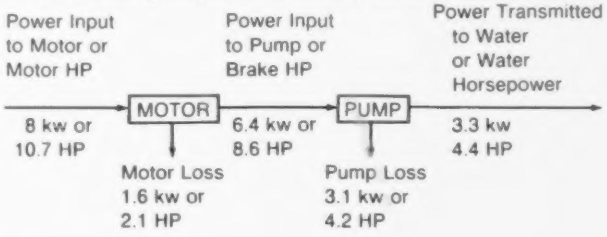
Calculate the power output of the pump or water horsepower:

$$\text{Water Horsepower, HP} = \frac{(\text{Flow GPM})(\text{Head, ft})}{3960}$$
$$= \frac{(357\text{ GPM})(48.47\text{ ft})}{3960}$$
$$= 4.4\text{ HP}$$

To estimate the efficiency of the pump, measure the kilowatts drawn by the pump motor. Assume the meter indicates 8000 watts or 8 kilowatts. The manufacturer claims the electric motor is 80% efficient.

$$\text{Brake Horsepower, HP} = (\text{Power to elec. motor})(\text{motor eff.})$$
$$= \frac{(8\text{ kw})(0.80)}{0.746\text{ kw/HP}}$$
$$= 8.6\text{ HP}$$
$$\text{Pump Efficiency, \%} = \frac{\text{Water Horsepower, HP} \times 100\%}{\text{Brake Horsepower, HP}}$$
$$= \frac{4.4\text{ HP} \times 100\%}{8.6\text{ HP}}$$
$$= 51\%$$

The following diagram may clarify the above problem:


Power Input to Motor or Motor HP
Power Input to Pump or Brake HP
Power Transmitted to Water or Water Horsepower
MOTOR
PUMP
8 kw or 10.7 HP
6.4 kw or 8.6 HP
3.3 kw 4.4 HP
Motor Loss 1.6 kw or 2.1 HP
Pump Loss 3.1 kw or 4.2 HP

The wire-to-water efficiency is the efficiency of the power input to produce water horsepower.

$$\text{Wire-to-Water Efficiency, \%} = \frac{\text{Water Horsepower, HP}}{\text{Power Input, HP}} \times 100\%$$

$$= \frac{4.4\text{ HP}}{10.7\text{ HP}} \times 100\%$$

$$= 41\%$$

A.87 Pump Speed — Performance Relationships

Changing the velocity of a centrifugal pump will change its operating characteristics. If the speed of a pump is changed, the flow, head developed, and power requirements will change. The operating characteristics of the pump will change with speed approximately as follows:

$$\text{Flow, } Q_n = \left[\frac{N_n}{N_r}\right] Q_r$$

$$\text{Head, } H_n = \left[\frac{N_n}{N_r}\right]^2 H_r$$

$$\text{Power, } P_n = \left[\frac{N_n}{N_p}\right]^3 P_r$$

r = rated

n = now

N = pump speed

Actually, pump efficiency does vary with speed; therefore, these formulas are not quite correct. If speeds do not vary by more than a factor of two (if the speeds are not doubled or cut in half), the results are close enough. Other factors contributing to changes in pump characteristic curves include impeller wear and roughness in pipes.

Example: To illustrate these relationships, assume a pump has a rated capacity of 600 GPM, develops 100 ft of head, and has a power requirement of 15 HP when operating at 1500 rpm. If the efficiency remains constant, what will be the operating characteristics if the speed drops to 1200 rpm?

Calculate new flow rate or capacity:

$$\text{Flow, } Q_n = \left[\frac{N_n}{N_r}\right] Q_r$$

$$= \left[\frac{1200\text{ rpm}}{1500\text{ rpm}}\right] 600\text{ GPM}$$

$$= \left[\frac{4}{5}\right] 600\text{ GPM}$$

$$= (4)(120\text{ GPM})$$

$$= 480\text{ GPM}$$

Calculate new head:

$$\text{Head, } H_n = \left[\frac{N_n}{N_r}\right]^2 H_r$$

$$= \left[\frac{1200\text{ rpm}}{1500\text{ rpm}}\right]^2 100\text{ ft}$$

$$= \left(\frac{4}{5}\right)^2 100\text{ ft}$$

$$= \left(\frac{16}{25}\right)(100\text{ ft})$$

$$= 16\ (4\text{ ft})$$

$$= 64\text{ ft}$$

Calculate new power requirement:

$$\text{Power, } P_n = \left[\frac{N_n}{N_r}\right]^3 P_r$$

$$= \left(\frac{1200\text{ rpm}}{1500\text{ rpm}}\right)^3 15\text{ HP}$$

$$= \left(\frac{4}{5}\right)^3 15\text{ HP}$$

$$= \left(\frac{64}{125}\right) 15\text{ HP}$$

$$= \left(\frac{64}{25}\right)(3\text{ HP})$$

$$= 7.7\text{ HP}$$

A.88 Friction or Energy Losses

Whenever water flows through pipes, valves and fittings, energy is lost due to pipe friction (resistance), friction in valves and fittings, and the turbulence resulting from the flowing water changing its direction. Figure A.1 can be used to convert the friction losses through valves and fittings to lengths of straight pipe that would produce the same amount of friction losses. To estimate the friction or energy losses resulting from water flowing in a pipe system, we need to know:

1. Water flow rate,
2. Pipe size or diameter and length, and
3. Number, size and type of valve fittings.

An easy way to estimate friction or energy losses is to follow the following steps:

1. Determine the flow rate;
2. Determine the diameter and length of pipe;
3. Convert all valves and fittings to equivalent lengths of straight pipe (see Figure A.1);
4. Add up total length of equivalent straight pipe; and
5. Estimate friction or energy losses by using Figure A.2. With the flow in GPM and diameter of pipe, find the friction loss per 100 feet of pipe. Multiply this value by equivalent length of straight pipe.

The procedure for using FIgure A.1 is very easy. Locate the type of valve or fitting you wish to convert to an equivalent pipe length; find its diameter on the right-hand scale; and draw a straight line between these two points to locate the equivalent length of straight pipe.

Example: Estimate the friction losses in the piping system of a pump station when the flow is 1,000 GPM. The 8-inch suction line is 10 feet long and contains a 90-degree bend (long sweep elbow), a gate valve and an 8-inch by 6-inch reducer at the inlet to the pump. The 6-inch discharge line is 30 feet long and contains a check valve, a gate valve, and three 90-degree bends (medium sweep elbows):

Example

The dotted line shows that the resistance of a 6-inch Standard Elbow is equivalent to approximately 16 feet of 6-inch Standard Pipe.

Note

For sudden enlargements or sudden contractions, use the smaller diameter, d, on the pipe size scale.

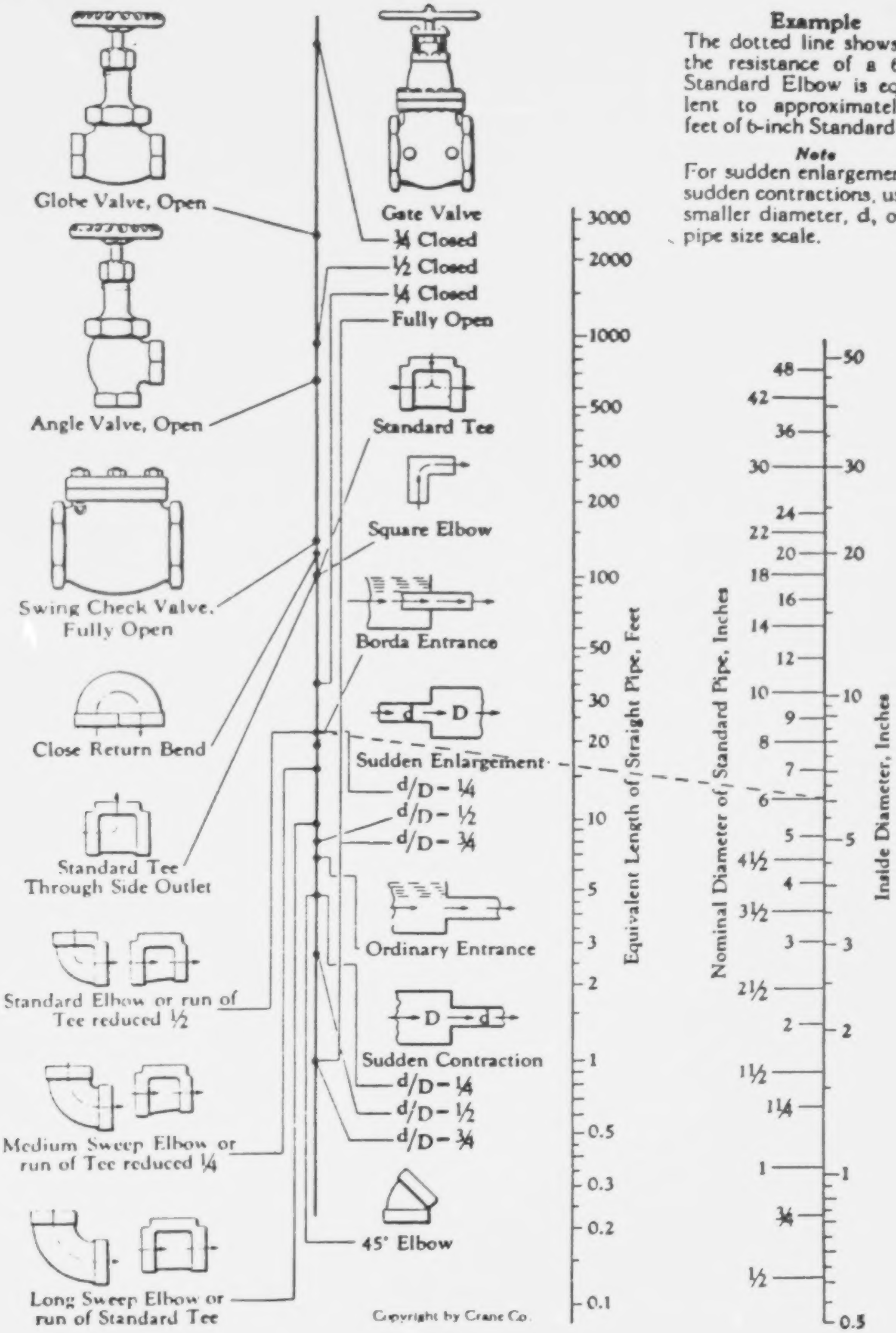

Globe Valve, Open
Gate Valve
¾ Closed
½ Closed
¼ Closed
Fully Open
Angle Valve, Open
Standard Tee
Square Elbow
Swing Check Valve, Fully Open
Borda Entrance
Close Return Bend
Sudden Enlargement
d/D – ¼
d/D – ½
d/D – ¾
Standard Tee Through Side Outlet
Ordinary Entrance
Standard Elbow or run of Tee reduced ½
Sudden Contraction
d/D – ¼
d/D – ½
d/D – ¾
Medium Sweep Elbow or run of Tee reduced ¼
45° Elbow
Long Sweep Elbow or run of Standard Tee
Equivalent Length of Straight Pipe, Feet
3000
2000
1000
500
300
200
100
50
30
20
10
5
3
2
1
0.5
0.3
0.2
0.1
Nominal Diameter of Standard Pipe, Inches
48
42
36
30
24
22
20
18
16
14
12
10
9
8
7
6
5
4½
4
3½
3
2½
2
1½
1¼
1
¾
½
Inside Diameter, Inches
50
30
20
10
5
3
2
1
0.5

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Fig. A.1 Resistance of valves and fittings to flow of water

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U.S. GPM	0.5 in.		0.75 in.		1 in.		1.25 in.		1.5 in.		2 in.		2.5 in.	
	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.
10	10.56	95.9	6.02	23.0	3.71	6.86	2.15	1.77	1.58	.83	.96	.25	.67	.11
20			12.0	86.1	7.42	25.1	4.29	6.34	3.15	2.94	1.91	.87	1.34	.36
30					11.1	54.6	6.44	13.6	4.73	6.26	2.87	1.82	2.01	.75
40					14.8	95.	8.58	23.5	6.30	10.79	3.82	3.10	2.68	1.28
50							10.7	36.0	7.88	16.4	4.78	4.67	3.35	1.94
60							12.9	51.0	9.46	23.2	5.74	6.59	4.02	2.72
70							15.0	68.8	11.03	31.3	6.69	8.86	4.69	3.63
80							17.2	89.2	12.6	40.5	7.65	11.4	5.36	4.66
90									14.2	51.0	8.60	14.2	6.03	5.82
100									15.8	62.2	9.56	17.4	6.70	7.11
120									18.9	88.3	11.5	24.7	8.04	10.0
140											13.4	33.2	9.38	13.5
160											15.3	43.0	10.7	17.4
180											17.2	54.1	12.1	21.9
200											19.1	66.3	13.4	26.7
220											21.0	80.0	14.7	32.2
240											22.9	95.0	16.1	38.1
260													17.4	44.5
280													18.8	51.3
300													20.1	58.5
350													23.5	79.2

U.S. GPM	3 in.		4 in.		5 in.		6 in.		8 in.		10 in.		12 in.		14 in.		16 in.		18 in.		20 in.	
	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.	Vol.	Frict.
20	.91	.15																				
40	1.82	.55	1.02	.13																		
50	2.72	1.17	1.53	.28	.96	.08																
80	3.63	2.02	2.04	.48	1.28	.14	.91	.06														
100	4.54	3.10	2.55	.73	1.60	.20	1.13	.10														
120	5.45	4.40	3.06	1.03	1.92	.29	1.36	.13														
140	6.35	5.93	3.57	1.38	2.25	.38	1.59	.18														
160	7.26	7.71	4.08	1.78	2.57	.49	1.82	.23														
180	8.17	9.73	4.60	2.24	2.89	.61	2.04	.28														
200	9.08	11.9	5.11	2.74	3.21	.74	2.27	.35														
220	9.98	14.3	5.62	3.28	3.53	.88	2.50	.42	1.40	.10												
240	10.9	17.0	6.13	3.88	3.85	1.04	2.72	.49	1.53	.12												
260	11.8	19.8	6.64	4.54	4.17	1.20	2.95	.57	1.66	.14												
280	12.7	22.8	7.15	5.25	4.49	1.38	3.18	.66	1.79	.16												
300	13.6	26.1	7.66	6.03	4.81	1.58	3.40	.75	1.91	.18												
350			8.94	8.22	5.61	2.11	3.97	1.01	2.24	.24												
400			10.20	10.7	6.41	2.72	4.54	1.30	2.55	.30												
460			11.45	13.4	7.22	3.41	5.11	1.64	2.87	.38	1.84	.12										
500			12.8	16.6	8.02	4.16	5.67	2.02	3.19	.46	2.04	.15	1.42	.06								
550			14.0	19.9	8.82	4.98	6.24	2.42	3.51	.56	2.25	.18	1.56	.07								
600					9.62	5.88	6.81	2.84	3.83	.66	2.45	.21	1.70	.08	1.25	.04						
700					11.2	7.93	7.94	3.87	4.47	.88	2.86	.29	1.99	.12	1.46	.05						
800					12.8	10.22	9.08	5.06	5.11	1.14	3.27	.37	2.27	.15	1.67	.07						
900					14.4	12.9	10.2	6.34	5.74	1.44	3.68	.46	2.55	.18	1.88	.09						
1000							11.3	7.73	6.38	1.76	4.09	.57	2.84	.22	2.08	.11						
1100							12.5	9.80	7.02	2.14	4.49	.68	3.12	.27	2.29	.13						
1200							13.6	11.2	7.66	2.53	4.90	.81	3.40	.32	2.50	.15	1.91	.08				
1300							14.7	13.0	8.30	2.94	6.31	.95	3.69	.37	2.71	.17	2.07	.09				
1400									8.93	3.40	5.72	1.09	3.97	.43	2.92	.20	2.23	.10				
1500									9.57	3.91	6.13	1.25	4.26	.49	3.13	.23	2.34	.12				
1600									10.2	4.45	6.54	1.42	4.54	.55	3.33	.25	2.55	.13	2.02	.07		
1700									10.8	5.00	6.94	1.60	4.87	.62	3.54	.29	2.71	.15	2.15	.08		
1800									11.5	5.58	7.35	1.78	5.11	.70	3.75	.32	2.87	.16	2.27	.09		
1900									12.1	6.19	7.76	1.97	5.39	.77	3.96	.35	3.03	.18	2.40	.10		
2000									12.8	6.84	8.17	2.17	5.67	.86	4.17	.39	3.19	.20	2.52	.11		
2500											10.2	3.38	7.10	1.33	5.21	.60	3.99	.31	3.15	.17		
3000											12.3	4.79	8.51	1.88	6.25	.86	4.79	.44	3.78	.24	3.06	.14
3500											14.3	6.55	9.93	2.56	7.29	1.16	5.58	.58	4.41	.32	3.57	.19
4000													11.3	3.31	8.34	1.50	6.38	.75	5.04	.42	4.08	.24
4500													12.8	4.18	9.38	1.88	7.18	.95	5.67	.53	4.59	.31
5000													14.7	5.13	10.4	2.30	7.98	1.17	6.30	.65	5.11	.38
6000															12.5	3.31	9.57	1.66	7.56	.92	6.13	.53
7000															14.6	4.50	11.2	2.26	8.83	1.24	7.15	.72
8000																	12.8	2.96	10.09	1.61	8.17	.94
9000																	14.4	3.73	11.3	2.02	9.19	1.18
10000																			12.6	2.48	10.2	1.45

No allowance has been made for age, differences in diameter, or any other abnormal condition of interior surface. Any Factor of Safety must be estimated from the local conditions and the requirements of each particular installation. For general purposes, 15% is a responsible Factor of Safety.

Fig. A.2 Friction Loss for Water in Feet Per 100 Feet of Pipe

(Reprinted from the 10th Edition of the Standards of the Hydraulic Institute, 122 East 42nd Street, New York)

SUCTION LINE (8-inch diameter)

Item	Equivalent Length, ft
1. Length of pipe	10
2. 90-degree bend	14
3. Gate valve	4
4. 8-inch by 6-inch reducer	17
5. Ordinary entrance	12
Total equivalent length	57 feet

Friction loss (Fig. A.2) = 1.76 ft/100 ft of pipe

DISCHARGE LINE (6-inch diameter)

Item	Equivalent Length, ft
1. Length of pipe	30
2. Check valve	38
3. Gate valve	4
4. Three 90-degree bends (3) (14)	42
Total equivalent length	114 feet

Friction loss (Fig. A.2) = 7.73 ft/100 ft of pipe

Estimate the total friction losses in pumping system for a flow of 1,000 GPM.

SUCTION

Loss = (1.76 ft/100 ft) (57 ft) = 1.0 Ft

DISCHARGE

Loss = (7.73 ft/100 ft) (114 ft) = 8.8 ft

Total friction losses, ft = 9.8 ft

A.9 STEPS IN SOLVING PROBLEMS

A.90 Identification of Problem

To solve any problem, you have to identify the problem, determine what kind of answer is needed, and collect the information needed to solve the problem. A good approach to this type of problem is to examine the problem and make a list of *KNOWN* and *UNKNOWN* information.

Example: Find the theoretical detention time in a rectangular sedimentation tank 8 feet deep, 30 feet wide, and 60 feet long when the flow is 1.4 MGD.

Known		Unknown
Depth	= 8 ft	Detention Time, hours
Width	= 30 ft	
Length	= 60 ft	
Flow	= 1.4 MGD	

Sometimes a drawing or sketch will help to illustrate a problem and indicate the knowns, unknowns, and possibly additional information needed.

A.91 Selection of Formula

Most problems involving mathematics in water treatment plant operation can be solved by selecting the proper formula, inserting the known information, and calculating the unknown. In our example, we could look in Chapter 4, "Sedimentation," or in Section A.11 of this chapter, "Basic Formulas," to find a formula for calculating detention time. From Section A.11:

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

To convert the known information to fit the terms in a formula sometimes requires extra calculations. The next step is to find the values of any terms in the formula that are not in the list of known values.

$$\begin{aligned}\text{Flow, gal/day} &= 1.4\text{ MGD}\\ &= 1{,}400{,}000\text{ gal/day}\end{aligned}$$

From Section A.30:

$$\begin{aligned}\text{Tank Volume, cu ft} &= (\text{Length, ft})(\text{Width, ft})(\text{Height, ft})\\ &= 60\text{ ft} \times 30\text{ ft} \times 8\text{ ft}\\ &= 14{,}400\text{ cu ft}\end{aligned}$$

Solution of Problem:

$$\begin{aligned}\text{Detention Time, hrs} &= \frac{(\text{Tank Volume, cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}\\ &= \frac{(14{,}400\text{ cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{1{,}400{,}000\text{ gal/day}}\\ &= 1.85\text{ hr}\end{aligned}$$

The remainder of this section discusses the details that must be considered in solving this problem.

A.92 Arrangement of Formula

Once the proper formula is selected, you may have to rearrange the terms to solve for the unknown term. From Section A.71, "Flow Rate," we can develop the formula:

$$\text{Velocity, ft/sec} = \frac{\text{Flow Rate, cu ft/sec}}{\text{Cross-Sectional Area, sq ft}}$$

or

$$V = \frac{Q}{A}$$

In this equation if Q and A were given, the equation could be solved for V. If V and A were known, the equation would have to be rearranged to solve for Q. To move terms from one side of an equation to another, use the following rule:

When moving a term or number from one side of an equation to the other, move the numerator (top) of one side to denominator (bottom) of the other; or from the denominator (bottom) of one side to the numerator (top) of the other.

$$V = \frac{Q}{A} \text{ or } Q = AV \text{ or } A = \frac{Q}{V}$$

If the volume of a sedimentation tank and the desired detention time were given, the detention time formula could be rearranged to calculate the design flow.

$$\text{Detention Time, hrs} = \frac{(\text{Tank Vol., cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

By rearranging the terms

$$\text{Flow, gal/day} = \frac{(\text{Tank Vol., cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Detention Time, hrs}}$$

A.93 Unit Conversions

Each term in a formula or mathematical calculation must be of the correct units. The area of a rectangular clarifier (Area, sq ft = Length, ft × Width, ft) can't be calculated in square feet if the width is given as 246 inches or 20 feet 6 inches. The width must be converted to 20.5 feet. In the example problem, if the tank volume were given in gallons, then the 7.48 gal/cu ft would not be needed. THE UNITS IN A FORMULA MUST ALWAYS BE CHECKED BEFORE ANY CALCULATIONS ARE PERFORMED TO AVOID TIME-CONSUMING MISTAKES.

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{\cancel{\text{cu ft}}}{\ } \times \frac{\cancel{\text{gal}}}{\cancel{\text{cu ft}}} \times \frac{\text{hr}}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{\cancel{\text{gal}}}$$

$$= \text{hr (all other units cancel)}$$

NOTE: We have hours = hr. One should note that the hour unit on both sides of the equation can be cancelled out and nothing would remain. This is one more check that we have the correct units. By rearranging the detention time formula, other unknowns could be determined.

If the design detention time and design flow were known, the required capacity of the tank could be calculated.

$$\text{Tank Volume, cu ft} = \frac{(\text{Detention Time, hr})(\text{Flow, gal/day})}{(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}$$

If the tank volume and design detention time were known, the design flow could be calculated.

$$\text{Flow, gal/day} = \frac{(\text{Tank Volume, cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}{\text{Detention Time, hrs}}$$

Rearrangement of the detention time formula to find other unknowns illustrates the need to always use the correct units.

A.94 Calculations

Sections A.12, "Multiplication," and A.13, "Division," outline the steps to follow in mathematical calculations. In general, do the calculations inside parentheses ( ) first and brackets [ ] next. Calculations should be done above and below the divison line before dividing.

$$\text{Detention Time, hrs} = \frac{[(\text{Tank, Volume, cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})]}{\text{Flow, gal/day}}$$

$$= \frac{[(14{,}400\ \text{cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})]}{1{,}400{,}000\ \text{gal/day}}$$

$$= \frac{2{,}585{,}088\ \text{gal-hr/day}}{1{,}400{,}000\ \text{gal/day}}$$

$$= 1.85,\ \text{or}$$

$$= 1.9\ \text{hr}$$

A.95 Significant Figures

In calculating the detention time in the previous section, the answer is given as 1.9 hr. The answer could have been calculated:

$$\text{Detention Time, hrs} = \frac{2{,}585{,}088\ \text{gal-hr/day}}{1{,}400{,}000\ \text{gal/day}}$$

$$= 1.846491429\ldots\ \text{hours}$$

How does one know when to stop dividing? Common sense and significant figures both help.

First, consider the meaning of detention time and the measurements that were taken to determine the knowns in the formula. Detention time in a tank is a theoretical value and assumes that all particles of water throughout the tank move through the tank at the same velocity. This assumption is not correct; therefore, detention time can only be a representative time for some of the water particles.

Will the flow of 1.4 MGD be constant throughout the 1.9 hours, and is the flow exactly 1.4 MGD, or could it be 1.35 MGD or 1.428 MGD? A carefully calibrated flow meter may give a reading within 2% of the actual flow rate. Flows into a tank fluctuate and flow meters do not measure flows extremely accurately; so the detention time again appears to be a representative or typical detention time.

Tank dimensions are probably satisfactory within 0.1 ft. A flow meter reading of 1.4 MGD is less precise and it could be 1.3 or 1.5 MGD. A 0.1 MGD flow meter error when the flow is 1.4 MGD is (0.1/1.4) × 100% = 7% error. A detention time of 1.9 hours, based on a flow meter reading error of plus or minus 7%, also could have the same error or more, even if the flow was constant. Therefore, the detention time error could be 1.9 hours × 0.07 = ±0.13 hours.

In most of the calculations in the operation of water treatment plants, the operator uses measurements determined in the lab or read from charts, scales, or meters. The accuracy of every measurement depends on the sample being measured, the equipment doing the measuring, and the operator reading or measuring the results. Your estimate is no better than the least precise measurement. Do not retain more than one doubtful number.

To determine how many figures or numbers mean anything in an answer, the approach called "significant figures" is used. In the example the flow was given in two significant figures (1.4 MGD), and the tank dimensions could be considered accurate to the nearest tenth of a foot (depth = 9.0 ft) or two significant figures. Since all measurements and the constants contained two significant figures, the results should be reported as two significant figures or 1.9 hours. The calculations are normally carried out to three significant figures (1.85 hours) and rounded off to two significant figures (1.9 hours).

Decimal points require special attention when determining the number of significant figures in a measurement.

Measurement	Significant Figures
0.00325	3
11.078	5
21,000.	2

Example: The distance between two points was divided into three sections, and each section was measured by a different group. What is the distance between the two points if each group reported the distance if measured as follows:

Group	Distance, ft	Significant Figures
A	11,300.	3
B	2,438.9	5
C	87.62	4
Total Distance	13,826.52	

Group A reported the length of the section it measured to three significant figures; therefore, the distance between the two points should be reported as 13,800 feet (3 significant figures).

When adding, substracting, multiplying, or dividing, the number of significant figures in the answer should not be more than the term in the calculations with the least number of significant figures.

A.96 Check Your Results

After having completed your calculations, you should carefully examine your calculations and answer. Does the answer seem reasonable? If possible, have another operator check your calculations before making any operational changes.

A.10 BASIC CONVERSION FACTORS (ENGLISH SYSTEM)

UNITS		
1,000,000	= 1 Million	1,000,000/1 Million
LENGTH		
12 in	= 1 ft	12 in/ft
3 ft	= 1 yd	3 ft/yd
5280 ft	= 1 mi	5280 ft/mi
AREA		
144 sq in	= 1 sq ft	144 sq in/sq ft
43,560 sq ft	= 1 acre	43,560 sq ft/ac
VOLUME		
7.48 gal	= 1 cu ft	7.48 gal/cu ft
1000 m*L*	= 1 liter	1000 m*L*/*L*
3.785 *L*	= 1 gal	3.785 *L*/gal
231 cu in	= 1 gal	231 cu in/gal
WEIGHT		
1000 mg	= 1 gm	1000 mg/gm
1000 gm	= 1 kg	1000 gm/kg
454 gm	= 1 lb	454 gm/lb
2.2 lbs	= 1 kg	2.2 lbs/kg
POWER		
0.746 kw	= 1 HP	0.746 kw/HP
DENSITY		
8.34 lbs	= 1 gal	8.34 lbs/gal
62.4 lbs	= 1 cu ft	62.4 lbs/cu ft
DOSAGE		
17.1 mg/*L*	= 1 grain/gal	17.1 mg/*L*/gpg
64.8 grains	= 1 mg	64.8 grains/mg
PRESSURE		
2.31 ft water	= 1 psi	2.31 ft water/psi
0.433 psi	= 1 ft water	0.433 psi/ft water
1.133 ft water	= 1 in Mercury	1.133 ft water/in Mercury
FLOW		
694 GPM	= 1 MGD	694 GPM/MGD
1.55 CFS	= 1 MGD	1.55 CFS/MGD
TIME		
60 sec	= 1 min	60 sec/min
60 min	= 1 hr	60 min/hr
24 hr	= 1 day	24 hr/day

NOTE: In our equations the values in the right hand column may be written either as 24 hr/day or 1 day/24 hours depending on which units we wish to convert or our desired results.

A.11 BASIC FORMULAS

FLOWS

1. $$\text{Flow, MGD} = \frac{(\text{Flow, GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

or

$$\text{Flow, GPM} = \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}$$

CHEMICAL DOSES

2. $$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

Calibration of a Dry Chemical Feeder

3. $$\text{Chemical Feed, lbs/day} = \frac{\text{Chemical Applied, lbs}}{\text{Length of Application, day}}$$

Calibration of a Solution Chemical Feeder (Chemical Feed Pump or a Hypochlorinator)

4. $$\text{Chemical Feed, lbs/day} = \frac{(\text{Chem Conc., mg/}L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

WELLS

5. $$\text{Chlorine Required, gal} = \frac{(\text{Casing Volume, gal})(\text{Desired Dose, mg/}L)}{\text{Chlorine Solution, mg/}L}$$

SMALL WATER TREATMENT PLANTS

6. $$\text{Chemical Feeder Setting, GPD} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg/}L)(8.34\text{ lbs/gal})}{\text{Liquid Alum, lbs/gal}}$$

7. $$\text{Detention Time, hr} = \frac{(\text{Volume, gal})(24\text{ hr/day})}{(\text{Flow, gal/day})}$$

$$\text{Detention Time, hr} = \frac{(\text{Volume, cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

8. $$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, GPD}}{\text{Surface Area, sq ft}}$$

9. $$\text{Weir Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Weir Length, ft}}$$

10. $$\text{Filtration, Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

11. $$\text{Backwash Rate, GPM/sq ft} = \frac{\text{Backwash Flow, GPM}}{\text{Surface Area, sq ft}}$$

12. $$\text{Ion Exchange Capacity, grains} = (\text{Media Vol, cu ft})(\text{Removal Capacity, gr/cu ft})$$

DISINFECTION

13. $$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

13a. $$\text{Sodium Hypochlorite Solution, gal} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\text{ lbs/gal})(\text{Hypochlorite, }\%)}$$

14. To disinfect a main use the same formulas as in 31 to disinfect a well.

15. To disinfect a storage tank use the same formulas as in 31 to disinfect a well.

16. $$\text{Actual Dose, mg/}L = \frac{\text{Chlorine, lbs}}{(\text{Volume, of Water, M Gal})(8.34\text{ lbs/gal})}$$

17. Chlorine Feed, lbs/day = (Flow, MGD)(Dose, mg/L)(8.34 lbs/gal)

18. Chlorine Demand, mg/L = Chlorine Dose, mg/L − Chlorine Residual, mg/L

19. Hypochlorite, gal = (Container Area, sq ft)(Drawdown, ft)(7.48 gal/cu ft)

20. $$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, gal/day})(8.34\ \text{lbs/gal})}$$

21. $$\text{Water Added, gal (to Hypochlorite Solution)} = \frac{(\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Hypo, gal})(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

LABORATORY PROCEDURES

22. $$\text{Temperature, °C} = \frac{(5)}{9}(°\text{F} - 32°\text{F})$$

23. $$\text{Temperature, °F} = \frac{9}{5}(°\text{C}) + 32°\text{F}$$

A.12 HOW TO USE THE BASIC FORMULAS

One clever way of using the basic formulas is to use the Davidson[1] Pie Method. To apply this method to the first basic formula,

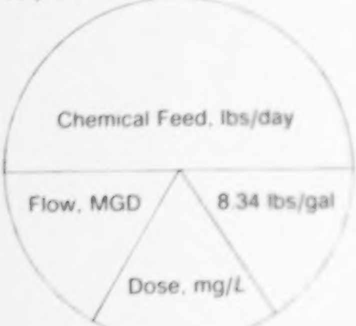
1. Chemical Feeder, lbs/day = (Flow, MGD)(Dose,mg/L)(8.34 lbs/gal)

(a) Draw a circle and draw a horizontal line through the middle of the circle;

(b) Write the Chemical Feed, lbs/day in the top half;

(c) Divide the bottom half into three parts; and

(d) Write Flow, MGD; Dose, mg/L, and 8.34 lbs/gal in the other three parts.



If you want to find the Chemical Feed, lbs/day, cover up the Chemical Feed, and what is left uncovered will give you the correct formula.

2. Chemical Feed, lbs/day = (Flow, MGD)(Dose, mg/L)(8.34 lbs/gal)

If you know the chlorinator setting in pounds per day and the flow in MGD and would like to know the dose in mg/L, cover up the Dose, mg/L, and what is left uncovered will give you the correct formula.

3. $$\text{Dose, mg/}L = \frac{\text{Chemical Feed, lbs/day}}{(\text{Flow, MGD})(8.34\ \text{lbs/gal})}$$

Another approach to using the basic formulas is to memorize the basic formula, for example the detention time formula.

4. $$\text{Detention Time, hr} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

This formula works fine to solve for the detention time when the Tank Volume, gal, and Flow, gal/day, are given.

If you wish to determine the Flow, gal/day, when the Detention Time, hr, and Tank Volume, gal, are given, you must change the basic formula. You want the Flow, gal/day, on the left of the equal sign and everything else on the right of the equal sign. This is done by moving the terms diagonally (from top to bottom or from bottom to top) past the equal sign.

4. $$\boxed{\text{Detention Time, hr}} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\boxed{\text{Flow, gal/day}}}$$

or

$$\text{Flow, gal/day} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\text{Detention Time, hr}}$$

This same approach can be used if the Tank Volume, gal, was unknown and the Detention Time, hr, and Flow, gal/day, were given. We want Tank Volume, gal, on one side of the equation and everything else on the other side.

4. $$\text{Detention Time, hr} = \frac{(\text{Tank Volume, gal})\boxed{(24\ \text{hr/day})}}{\boxed{\text{Flow, gal/day}}}$$

To Top

To Bottom

or

$$\frac{(\text{Detention Time, hr})(\text{Flow, gal/day})}{24\ \text{hr/day}} = \text{Tank Volume, gal}$$

or

$$\text{Tank Volume, gal} = \frac{(\text{Detention Time, hr})(\text{Flow, gal/day})}{24\ \text{hr/day}}$$

One more check is to be sure the units in the rearranged formula cancel out correctly.

For additional information on the use of the basic formulas, refer to Sections:

A.91, "Selection of Formula,"

A.92, "Arrangement of Formula,"

A.93, "Unit Conversions," and

A.94, "Calculations."

A.13 TYPICAL SMALL WATER SYSTEM PROBLEMS (ENGLISH SYSTEM)

A.130 Flows

EXAMPLE 1

Convert a flow of 450 gallons per minute to million gallons per day.

Known	Unknown
Flow, GPM = 450 GPM	Flow, MGD

Convert flow from 450 GPM to MGD.

$$\text{Flow, MGD} = \frac{(\text{Flow, GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$

$$= \frac{(450\ \text{GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$

$$= 0.648\ \text{MGD}$$

---

[1] Gerald Davidson, Manager, Clear Lake Oaks Water District, Clear Lake Oaks, California.

A.131 Chemical Dose

EXAMPLE 2

Determine the chlorinator setting in pounds per 24 hours if a well pump delivers 300 GPM and the desired chlorine dose is 2.0 mg/*L*.

Known	Unknown
Flow, GPM = 300 GPM	Chlorinator Setting, lbs/24 hours
Chlorine Dose, mg/*L* = 2.0 mg/*L*	

1. Convert flow from gallons per minute to million gallons per day.

$$\text{Flow, MGD} = \frac{(\text{Flow, gal/min})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

$$= \frac{(300\text{ gal/min})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

$$= 0.432\text{ MGD}$$

NOTE: When we multiply an equation by $\frac{1\text{ Million}}{1{,}000{,}000}$ we do not change anything except the units. This is just like multiplying an equation by 12 inches/foot or 60 min/hr; all we are doing is changing units.

2. Determine the chlorinator setting in pounds per 24 hours or pounds per day.

$$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

$$= (0.432\text{ MGD})(2.0\text{ mg}/L)(8.34\text{ lbs/gal})$$

$$= 7.2\text{ lbs/day}$$

EXAMPLE 3

Determine the actual chemical dose or chemical feed in pounds per day from a dry chemical feeder. A bucket placed under the chemical feeder weighed 0.2 pounds empty and 2.6 pounds after 30 minutes.

Known	Unknown
Empty Bucket, lbs = 0.2 lbs	Chemical Feed, lbs/day
Full Bucket, lbs = 2.6 lbs	
Time to Fill, min = 30 min	

Determine the chemical feed in pounds of chemical per day.

$$\text{Chemical Feed, lbs/day} = \frac{\text{Chemical Applied, lbs}}{\text{Length of Application, days}}$$

$$= \frac{(2.6\text{ lbs} - 0.2\text{ lbs})(60\text{ min/hr})(24\text{ hr/day})}{30\text{ min}}$$

$$= 115\text{ lbs/day}$$

EXAMPLE 4

Determine the chemical feed in pounds of chlorine per day from a hypochlorinator. The hypochlorite solution is 1.4 percent or 14,000 mg chlorine per liter. During a test run the hypochlorinator delivers 400 m*L* during 12 minutes.

Known	Unknown
Cl Solution, % = 1.4%	Chemical Feed, lbs/day
Cl Conc, mg/*L* = 14,000 mg/*L*	
Vol Pumped, m*L* = 400 m*L*	
Time Pumped, min = 12 min	

Calculate the chlorine fed by the hypochlorinator in pounds of chlorine per day.

$$\text{Chlorine Feed, lbs/day} = \frac{(\text{Cl Conc, mg}/L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= \frac{(14{,}000\text{ mg}/L)(400\text{ m}L)(60\text{ min/hr})(24\text{ hr/day})}{(12\text{ min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= 1.48\text{ lbs/day}$$

$$\text{or} = 1.5\text{ lbs chlorine/day}$$

A.132 Wells

EXAMPLE 5

How much sodium hypochlorite is required to dose a well at 100 mg/*L*? The casing diameter is 18 inches (1.5 ft) and the length of water-filled casing is 80 feet. Sodium hypochlorite is 5.25 percent or 52,500 mg/*L* chlorine.

Known	Unknown
Casing Diameter, ft = 1.5 ft	Chlorine Required, gal
Casing Length, ft = 80 ft	
Chlorine Dose, mg/*L* = 100 mg/*L*	
Chlorine Solution, mg/*L* = 52,500 mg/*L*	

1. Calculate the water-filled casing volume in gallons.

$$\text{Casing Volume, gal} = (0.785)(\text{Casing Diam, ft})^2(\text{Length, ft})(7.48\text{ gal/cu ft})$$

$$= (0.785)(1.5\text{ ft})^2(80\text{ ft})(7.48\text{ gal/cu ft})$$

$$= 1057\text{ gal}$$

2. Calculate the required gallons of sodium hypochlorite.

$$\text{Chlorine Required, gal} = \frac{(\text{Casing Volume, gal})(\text{Desired Dose, mg}/L)}{\text{Chlorine Solution, mg}/L}$$

$$= \frac{(1057\text{ gal})(100\text{ mg}/L)}{52{,}500\text{ mg}/L}$$

$$= 2.0\text{ gallons}$$

A.133 Small Water Treatment Plants

EXAMPLE 6

The optimum dose of liquid alum from the jar tests is 13 mg/*L*. Determine the setting on the liquid alum chemical feeder in gallons per day when the flow is 1.1 MGD. The liquid alum delivered to the plant contains 5.36 pounds of alum per gallon of liquid solution.

Known	Unknown
Alum Dose, mg/*L* = 13 mg/*L*	Chemical Feeder Setting, GPD
Flow, MGD = 1.1 MGD	
Liquid Alum, lbs/gal = 5.36 lbs/gal	

Calculate the chemical feeder setting in gallons per day (GPD).

$$\text{Chemical Feeder Setting, GPD} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(8.34\text{ lbs/gal})}{\text{Liquid alum, lbs/gal}}$$

$$= \frac{(1.1\text{ MGD})(13\text{ mg}/L)(8.34\text{ lbs/gal})}{5.36\text{ lbs/gal}}$$

$$= 22.2\text{ GPD}$$

EXAMPLE 7

A rectangular settling basin that is eighteen-feet long, eight-feet wide, and the water is four-feet deep. It treats a flow of 50,000 gallons per day. Estimate the detention time or settling time in hours in the basin for this flow.

Known	Unknown
Length, ft = 18 ft	Detention Time, hr
Width, ft = 8 ft	
Depth, ft = 4 ft	
Flow, GPD = 50,000 GPD	

1. Calculate the basin volume in gallons.

$$\begin{aligned}\text{Basin Volume, cu ft} &= (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})\\ &= (18\text{ ft})(8\text{ ft})(4\text{ ft})\\ &= 576\text{ cu ft}\end{aligned}$$

$$\begin{aligned}\text{Basin Volume, gal} &= (\text{Basin Volume, cu ft})(7.48\text{ gal/cu ft})\\ &= 576\text{ cu ft})(7.48\text{ gal/cu ft})\\ &= 4{,}308\text{ gal}\end{aligned}$$

2. Calculate the detention time in hours.

$$\begin{aligned}\text{Detention Time, hr} &= \frac{(\text{Basin Volume, gal})(24\text{ hr/day})}{\text{Flow, gal/day}}\\ &= \frac{(4{,}308\text{ gal})(24\text{ hr/day})}{50{,}000\text{ gal/day}}\\ &= 2.07\text{ hr}\\ \text{or} &= 2.1\text{ hr}\end{aligned}$$

EXAMPLE 8

Estimate the surface overflow rate in gallons per day per square foot for a 20-foot diameter clarifier that treats a flow of 70,000 gallons per day.

Known	Unknown
Diameter, ft = 20 ft	Overflow Rate, GPD/sq ft
Flow, GPD = 70,000 GPD	

1. Calculate the surface area of the clarifier in square feet.

$$\begin{aligned}\text{Surface Area, sq ft} &= (0.785)(\text{Diameter, ft})^2\\ &= (0.785)(20\text{ ft})^2\\ &= 314\text{ sq ft}\end{aligned}$$

2. Determine the basin overflow rate in gallons per day per square foot.

$$\begin{aligned}\text{Overflow Rate, GPD/sq ft} &= \frac{\text{Flow, gal/day}}{\text{Surface Area, sq ft}}\\ &= \frac{70{,}000\text{ GPD}}{314\text{ sq ft}}\\ &= 223\text{ GPD/sq ft}\end{aligned}$$

EXAMPLE 9

A 20-foot diameter circular clarifier treats a flow of 0.1 MGD. Calculate the weir loading in gallons per minute per foot of weir length if the weir is on the outside edge of the clarifier.

Known	Unknown
Weir Diameter, ft = 20 ft	Weir Loading, GPM/ft
Flow, MGD = 0.1 MGD	

1. Calculate length of weir.

$$\begin{aligned}\text{Weir Length, ft} &= \pi(\text{Weir Diameter, ft})\\ &= (3.14)(20\text{ ft})\\ &= 62.8\text{ ft}\end{aligned}$$

2. Convert flow from million gallons per day to gallons per minute.

$$\begin{aligned}\text{Flow, GPM} &= \frac{(\text{Flow, M Gal/day})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}\\ &= \frac{(0.1\text{ MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}\\ &= 69.4\text{ GPM}\end{aligned}$$

3. Estimate the weir loading in gallons per minute per foot.

$$\begin{aligned}\text{Weir Loading, GPM/ft} &= \frac{\text{Flow, GPM}}{\text{Weir Length, ft}}\\ &= \frac{69.4\text{ GPM}}{62.8\text{ ft}}\\ &= 1.1\text{ GPM/ft}\end{aligned}$$

EXAMPLE 10

A 15-foot wide by 20-foot long sand filter treats a flow of 720 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

Known	Unknown
Width, ft = 15 ft	Filtration Rate, GPM/sq ft
Length, ft = 20 ft	
Flow, GPM = 720 GPM	

1. Calculate the surface area of the filter.

$$\begin{aligned}\text{Area, sq ft} &= (\text{Length, ft})(\text{Width, ft})\\ &= (20\text{ ft})(15\text{ ft})\\ &= 300\text{ sq ft}\end{aligned}$$

2. Determine the filtration rate in gallons per minute per square foot.

$$\begin{aligned}\text{Filtration Rate, GPM/sq ft} &= \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}\\ &= \frac{720\text{ GPM}}{300\text{ sq ft}}\\ &= 2.4\text{ GPM/sq ft}\end{aligned}$$

EXAMPLE 11

Calculate the backwash flow required in gallons per minute to backwash a 10-foot wide by 15-foot long filter if the desired backwash flow rate is 20 gallons per minute per square foot.

Known	Unknown
Width, ft = 10 ft	Backwash Flow, GPM
Length, ft = 15 ft	
Backwash Rate, GPM/sq ft = 20 GPM/sq ft	

1. Calculate the surface area of the filter.

$$\begin{aligned}\text{Area, sq ft} &= (\text{Length, ft})(\text{Width, ft})\\ &= (15\text{ ft})(10\text{ ft})\\ &= 300\text{ sq ft}\end{aligned}$$

2. Calculate the backwash flow in gallons per minute.

BASIC FORMULA

$$\text{Backwash Rate, GPM/sq ft} = \frac{\text{Backwash Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$\begin{aligned}\text{Backwash Flow, GPM} &= (\text{Backwash Rate, GPM/sq ft})(\text{Surface Area, sq ft})\\ &= (20\ \text{GPM/sq ft})(300\ \text{sq ft})\\ &= 6{,}000\ \text{GPM}\end{aligned}$$

EXAMPLE 12

Estimate the ion exchange capacity in grains of hardness for a zeolite softener containing 150 cubic feet of media with a hardness removal capacity of 25 kilograins per cubic foot of media.

Known	Unknown
Media Vol, cu ft = 150 cu ft	Ion Exchange Capacity, grains
Removal Capacity, gr/cu ft = 25,000 grains/cu ft	

Calculate the ion exchange capacity in grains of hardness.

$$\begin{aligned}\text{Ion Exchange Capacity, grains} &= (\text{Media Vol, cu ft})(\text{Removal Capacity, grains/cu ft})\\ &= (150\ \text{cu ft})(25{,}000\ \text{grains/cu ft})\\ &= 3{,}750{,}000\ \text{grains}\end{aligned}$$

A.134 Disinfection

EXAMPLE 13

How many gallons of five percent sodium hypochlorite will be needed to disinfect a well with a 15-inch diameter casing and well screen? The well is 180 feet deep and there is 75 feet of water in the well. Use an initial chlorine dose of 100 mg/*L*.

Known	Unknown
Hypochlorite, % = 5%	5% Hypochlorite, gal
Chlorine Dose, mg/*L* = 100 mg/*L*	
Diameter, in = 15 in	
Well Depth, ft = 180 ft	
Water Depth, ft = 75 ft	

1. Calculate the volume of water in the well in gallons.

$$\begin{aligned}\text{Water Vol, gal} &= (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft})\\ &= \frac{(0.785)(15\ \text{in})^2(75\ \text{ft})(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}\\ &= 688\ \text{gal}\end{aligned}$$

2. Determine the pounds of chlorine needed.

$$\begin{aligned}\text{Chlorine, lbs} &= (\text{Volume, M Gal})(\text{Dose, mg/}L)(8.34\ \text{lbs/gal})\\ &= (0.000688\ \text{M Gal})(100\ \text{mg/}L)(8.34\ \text{lbs/gal})\\ &= 0.57\ \text{lbs chlorine}\end{aligned}$$

3. Calculate the gallons of five percent sodium hypochlorite solution needed.

$$\begin{aligned}\text{Sodium Hypochlorite Solution, gal} &= \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, \%})}\\ &= \frac{(0.57\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5\%)}\\ &= 1.37\ \text{gallons}\end{aligned}$$

Use 1.4 gallons of five percent sodium hypochlorite to disinfect the well.

EXAMPLE 14

A new 10-inch diameter water main 650-feet long needs to be disinfected. An initial chlorine dose of 400 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the three-hour disinfection period. How many gallons of 5.25 percent sodium hypochlorite solution will be needed?

Known	Unknown
Diameter of Pipe, in = 10 in	5.25% Hypochlorite, gal
Length of Pipe, ft = 650 ft	
Chlorine Dose, mg/*L* = 400 mg/*L*	
Hypochlorite, % = 5.25%	

1. Calculate the volume of water in the pipe in gallons.

$$\begin{aligned}\text{Pipe Volume, gal} &= (0.785)(\text{Diameter, ft})^2(\text{Length, ft})(7.48\ \text{gal/cu ft})\\ &= \frac{(0.785)(10\ \text{in})^2(650\ \text{ft})(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}\\ &= 2650\ \text{gal}\end{aligned}$$

2. Determine the pounds of chlorine needed.

$$\begin{aligned}\text{Chlorine, lbs} &= (\text{Volume, M Gal})(\text{Dose, mg/}L)(8.34\ \text{lbs/gal})\\ &= (0.00265\ \text{M Gal})(400\ \text{mg/}L)(8.34\ \text{lbs/gal})\\ &= 8.84\ \text{lbs chlorine}\end{aligned}$$

3. Calculate the gallons of 5.25 percent sodium hypochlorite solution needed.

$$\begin{aligned}\text{Sodium Hypochlorite Solution, gallons} &= \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, \%})}\\ &= \frac{(8.84\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5.25\%)}\\ &= 20.2\ \text{gallons}\end{aligned}$$

EXAMPLE 15

A service storage reservoir has been taken out of service for inspection, maintenance and repairs. The reservoir needs to be disinfected before being placed back on line. The reservoir is 30 feet in diameter and 8-feet deep. An initial chlorine dose of 100 mg/*L* is expected to maintain a chlorine residual of over 50 mg/*L* during the 24-hour disinfection period. How many gallons of 15 percent sodium hypochlorite solution will be needed?

Known	Unknown
Diameter, ft = 30 ft	15% Hypochlorite, gal
Tank Depth, ft = 8 ft	
Chlorine Dose, mg/*L* = 100 mg/*L*	
Hypochlorite, % = 15%	

1. Calculate the volume of water in the tank in gallons.

$$\begin{aligned}\text{Tank Volume, gal} &= (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft})\\ &= (0.785)(30\ \text{ft})^2(8\ \text{ft})(7.48\ \text{gal/cu ft})\\ &= 42{,}277\ \text{gal}\end{aligned}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$
$$= (0.042277\ \text{M Gal})(100\ \text{mg}/L)(8.34\ \text{lbs/gal})$$
$$= 35.3\ \text{lbs chlorine}$$

3. Calculate the gallons of 15 percent sodium hypochlorite solution needed.

$$\begin{matrix}\text{Sodium Hypochlorite}\\ \text{Sodium, gallons}\end{matrix} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$
$$= \frac{(35.3\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(15\%)}$$
$$= 28.2\ \text{gallons}$$

EXAMPLE 16

Calculate the actual chlorine dose in milligrams per liter if 200 gallons of a two percent sodium hypochlorite solution were used to treat two million gallons of water.

Known	Unknown
Volume Hypocl, gal = 200 gal	Chlorine Dose, mg/*L*
Volume Water, M Gal = 2 M Gal	
Hypochlorite, % = 2%	

1. Calculate the pounds of chlorine used.

$$\text{Chlorine, lbs} = \frac{(\text{Hypochlorite, gal})(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}{100\%}$$
$$= \frac{(200\ \text{gal})(8.34\ \text{lbs/gal})(2\%)}{100\%}$$
$$= 33.36\ \text{lbs chlorine}$$

2. Calculate the actual chlorine dose in milligrams per liter.

$$\begin{matrix}\text{Actual Dose,}\\ \text{mg}/L\end{matrix} = \frac{\text{Chlorine, lbs}}{(\text{Volume Water, M Gal})(8.34\ \text{lbs/gal})}$$
$$= \frac{33.36\ \text{lbs chlorine}}{(2\ \text{M Gal})(8.34\ \text{lbs/gal})}$$
$$= 2.0\ \text{mg}/L$$

EXAMPLE 17

A deep-well turbine pump delivers 250 GPM against typical operating heads. If the desired chlorine dose is 2.5 mg/*L*, what should be the chlorine feed rate in pounds per day?

Known	Unknown
Flow, GPM = 250 GPM	Chlorine Feed, lbs/day
Dose, mg/*L* = 2.5 mg/*L*	

1. Convert flow from gallons per minute to million gallons per day.

$$\text{Flow, MGD} = \frac{(\text{Flow, GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$
$$= \frac{(250\ \text{GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}$$
$$= 0.36\ \text{MGD}$$

2. Calculate the chlorine feed rate in pounds of chlorine per day.

$$\begin{matrix}\text{Chlorine Feed,}\\ \text{lbs/day}\end{matrix} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$
$$= (0.36\ \text{MGD})(2.5\ \text{mg}/L)(8.34\ \text{lbs/gal})$$
$$= 7.5\ \text{lbs/day}$$

EXAMPLE 18

Estimate the chlorine demand for a water in milligrams per liter if the chlorine dose is 2.6 mg/*L* and the chlorine residual is 0.4 mg/*L*.

Known	Unknown
Chlorine Dose, mg/*L* = 2.6 mg/*L*	Chlorine Demand, mg/*L*
Chlorine Residual, mg/*L* = 0.4 mg/*L*	

Estimate the chlorine demand in milligrams per liter.

$$\begin{matrix}\text{Chlorine Demand,}\\ \text{mg}/L\end{matrix} = \text{Chlorine Dose, mg}/L - \text{Chlorine Residual, mg}/L$$
$$= 2.6\ \text{mg}/L - 0.4\ \text{mg}/L$$
$$= 2.2\ \text{mg}/L$$

EXAMPLE 19

Estimate the gallons of hypochlorite pumped by a hypochlorinator if the hypochlorite solution is in a container with a diameter of three feet and the hypochlorite level drops 18 inches (1.5 feet) during a specific time period.

Known	Unknown
Diameter, ft = 3 ft	Hypochlorite Pumped, gal
Drop, ft = 1.5 ft	

Estimate the gallons of hypochlorite pumped.

$$\begin{matrix}\text{Hypochlorite,}\\ \text{gal}\end{matrix} = (\text{Container Area, sq ft})(\text{Drop, ft})(7.48\ \text{gal/cu ft})$$
$$= (0.785)(3\ \text{ft})^2(1.5\ \text{ft})(7.48\ \text{gal/cu ft})$$
$$= 79.3\ \text{gallons}$$

EXAMPLE 20

Estimate the desired strength (as a percent chlorine) of a hypochlorite solution being pumped by a hypochlorinator that delivers 80 gallons per day. The water being treated requires a chlorine feed rate of ten pounds of chlorine per day.

Known	Unknown
Hypochlorinator Flow, GPD = 80 GPD	Hypochlorite Strength, %
Chlorine Required, lbs/day = 10 lbs/day	

Estimate the desired hypochlorite strength as a percent chlorine.

$$\begin{matrix}\text{Hypochlorite}\\ \text{Strength, }\%\end{matrix} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, gal/day})(8.34\ \text{lbs/gal})}$$
$$= \frac{(10\ \text{lbs/day})(100\%)}{(80\ \text{GPD})(8.34\ \text{lbs/gal})}$$
$$= 1.5\%$$

EXAMPLE 21

How many gallons of water must be added to ten gallons of a five percent hypochlorite solution to produce a 1.5 percent hypochlorite solution?

Known		Unknown
Hypochlorite, gal	= 10 gal	Water Added, gal
Desired Hypochlorite, %	= 1.5%	
Actual Hypochlorite, %	= 5%	

Calculate the gallons of water that must be added to produce a 1.5 percent hypochlorite solution.

$$\text{Water Added, gal (to hypochlorite solution)} = \frac{(\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Hypo, gal})(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

$$= \frac{(10\text{ gal})(5\%) - (10\text{ gal})(1.5\%)}{1.5\%}$$

$$= \frac{50 - 15}{1.5}$$

$$= 23.3\text{ gallons}$$

A.135 Laboratory Procedures

EXAMPLE 22

Convert a temperature of 50°F to degrees Celsius.

Known	Unknown
Temp, °C = 59°F	Temp, °C

Change 59°F to degrees Celsius.

$$\text{Temperature, °C} = \frac{5(\text{°F} - 32\text{°F})}{9}$$

$$= \frac{5(59\text{°F} - 32\text{°F})}{9}$$

$$= 15\text{°C}$$

EXAMPLE 23

Convert a temperature of 5°C to degrees Fahrenheit.

Known	Unknown
Temp, °C = 5°C	Temp, °F

Change 5°C to degrees Fahrenheit.

$$\text{Temperature, °F} = \frac{9}{5}(\text{°C}) + 32\text{°F}$$

$$= \frac{(9)(5\text{°C})}{5} + 32\text{°F}$$

$$= 41\text{°F}$$

A.14 BASIC CONVERSION FACTORS (METRIC SYSTEM)

LENGTH		
100 cm	= 1 m	100 cm/m
3.281 ft	= 1 m	3.281 ft/m
AREA		
2.4711 ac	= 1 ha*	2.4711 ac/ha
10,000 sq m	= 1 ha	10,000 sq m/ha
VOLUME		
1000 m*L*	= 1 liter	1000 m*L*/*L*
1000 *L*	= 1 cu m	1000 *L*/cu m
3.785 *L*	= 1 gal	3.785 *L*/gal
WEIGHT		
1000 mg	= 1 gm	1000 mg/gm
1000 gm	= 1 kg	1000 gm/kg
DENSITY		
1 kg	= 1 liter	1 kg/*L*
PRESSURE		
10.015 m	= 1 kg/sq cm	10.015 m/kg/sq cm
1 Pascal	= 1 N/sq m	1 Pa/N/sq m
1 psi	= 6895 Pa	1 psi/6895 Pa
FLOW		
3785 cu m/day	= 1 MGD	3785 cu m/day/MGD
3.785 M*L*/day	= 1 MGD	3.785 M*L*/day/MGD

A.15 TYPICAL SMALL WATER SYSTEM PROBLEMS (METRIC SYSTEM)

A.150 Flows

EXAMPLE 1

Convert a flow of 500 gallons per minute to liters per second and cubic meters per day.

Known	Unknown
Flow, GPM = 500 GPM	1. Flow, liters/sec 2. Flow, cu m/day

1. Convert the flow from 500 GPM to liters per second.

$$\text{Flow, liters/sec} = \frac{(\text{Flow, gal/min})(3.785\text{ liters/gal})}{60\text{ sec/min}}$$

$$= \frac{(500\text{ gal/min})(3.785\text{ liters/gal})}{60\text{ sec/min}}$$

$$= 31.5\text{ liters/sec}$$

2. Convert the flow from 500 GPM to cubic meters per day.

$$\text{Flow, cu m/day} = \frac{(\text{Flow, gal/min})(3.785\ L\text{/gal})(60\text{ min/hr})(24\text{ hr/day})}{1000\ L\text{/cu m}}$$

$$= \frac{(500\text{ gal/min})(3.785\ L\text{/gal})(60\text{ min/hr})(24\text{ hr/day})}{1000\ L\text{ cu/m}}$$

$$= 2725\text{ cu m/day}$$

A.151 Chemical Doses

EXAMPLE 2

Determine the chlorinator setting in kilograms per 24 hours if 4000 cubic meters of water per day are to be treated with a desired chlorine dose of 2.5 mg/*L*.

Known		Unknown
Flow, cu m/day	= 4000 cu m/day	Chlorinator Setting, kg/24 hours
Chlorine Dose, mg/*L*	= 2.5 mg/*L*	

Determine the chlorinator setting in kilograms per 24 hours.

$$\text{Chlorinator Setting, kg/day} = \frac{(\text{Flow, cu m/day})(\text{Dose, mg/}L)(1{,}000\ L\text{/cu m})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}$$

$$= \frac{(4000\text{ cu m/day})(2.5\text{ mg/}L)(1{,}000\ L\text{/cu m})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}$$

$$= 10\text{ kg/day}$$

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*hectare

EXAMPLE 3

Determine the actual dose or chemical feed in kilograms per day from a dry chemical feeder. A bucket placed under the chemical feeder weighed 100 grams empty and 1400 grams after 30 minutes.

Known	Unknown
Empty Bucket, gm = 100 gm	Chemical Feed, kg/day
Full Bucket, gm = 1400 gm	
Time to fill, min = 30 min	

Determine the chemical feed in kilograms of chemical per day.

$$\text{Chemical Feeo, kg/day} = \frac{\text{Chemical Applied, kg}}{\text{Length of Application, days}}$$

$$= \frac{(1400\text{ gm} - 100\text{ gm})(60\text{ min/hr})(24\text{ hr/day})}{(1000\text{ gm/kg})(30\text{ min})}$$

$$= 62.4\text{ kg/day}$$

EXAMPLE 4

Determine the chemical feed in kilograms of chlorine per day from a hypochlorinator. The hypochlorite solution is 1.4 percent or 14,000 mg chlorine per liter. During a test run the hypochlorinator delivered 400 m*L* during 12 minutes.

Known	Unknown
Cl Solution, % = 1.4%	Chemical Feed, kg/day
Cl Conc, mg/*L* = 14,000 mg/*L*	
Vol Pumped, m*L* = 400 m*L*	
Time Pumped, min = 12 min	

Calculate the chlorine fed by the hypochlorinator in kilograms of chlorine per day.

$$\text{Chlorine Feed, kg/day} = \frac{(\text{Cl Conc, mg}/L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(1000\text{ gm/kg})}$$

$$= \frac{(14{,}000\text{ mg}/L)(400\text{ m}L)(60\text{ min/hr})(24\text{ hr/day})}{(12\text{ min})(1000\text{ m}L/L)(1000\text{ mg/gm})(1000\text{ gm/kg})}$$

$$= 0.67\text{ kg/day}$$

A.152 Wells

EXAMPLE 5

How much sodium hypochlorite is required to dose a well at 100 mg/*L*. The casing diameter is 50 cm (0.5 m) and the length of the water-filled casing is 24 meters. Sodium hypochlorite is 5.25 percent or 52,500 mg/*L* chlorine.

Known	Unknown
Casing Diameter, m = 0.5 m	Chlorine Required, *L*
Casing Length, m = 24 m	
Chlorine Dose, mg/*L* = 100 mg/*L*	
Chlorine Solution, mg/*L* = 52,500 mg/*L*	

1. Calculate the volume of the water filled casing in liters.

$$\text{Casing Volume, } L = (0.785)(\text{Diam, m})^2(\text{Length, m})(1000\ L/\text{cu m})$$

$$= (0.785)(0.5\text{ m})^2(24\text{ m})(1000\ L/\text{cu m})$$

$$= 4710\text{ liters}$$

2. Calculate the required liters of sodium hypochlorite.

$$\text{Chlorine Required, } L = \frac{(\text{Casing Volume, } L)(\text{Desired Dose, mg}/L)}{\text{Chlorine Solution, mg}/L}$$

$$= \frac{(4710\ L)(100\text{ mg}/L)}{52{,}500\text{ mg}/L}$$

$$= 9.0\text{ liters}$$

A.153 Small Water Treatment Plants

EXAMPLE 6

The optimum dose of liquid alum from the jar tests is 13 mg/*L*. Determine the setting on the liquid alum chemical feeder in liters per day and milliliters per minute when the flow is 4 M*L*D (mega or million liters per day). The liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of solution.

Known	Unknown
Alum Dose, mg/*L* = 13 mg/*L*	1. Chemical Feeder Setting, *L*/day
Flow, M*L*D = 4 M*L*D	
Liquid Alum = 642.3 mg/m*L*	2. Chemical Feeder Setting, m*L*/min

1. Calculate the chemical feeder setting in liters per day.

$$\text{Chemical Feeder Setting, } L\text{PD} = \frac{(\text{Flow, M}L\text{D})(\text{Alum Dose, mg}/L)(1{,}000{,}000)}{(\text{Liquid alum, mg/m}L)(1000\text{ m}L/L)(1\text{ Million})}$$

$$= \frac{(4\text{ M}L\text{D})(13\text{ mg}/L)(1{,}000{,}000)}{(642.3\text{ mg/m}L)(1000\text{ m}L/L)(1\text{ Million})}$$

$$= 81\ L\text{PD}$$

2. Calculate the chemical feeder setting in milliliters per minute.

$$\text{Chemical Feeder Setting, m}L\text{/min} = \frac{(\text{Flow, M}L\text{D})(\text{Alum Dose, mg}/L)(1{,}000{,}000)}{(\text{Liquid Alum, mg/m}L)(24\text{ hr/day})(60\text{ min/hr})(1\text{ Million})}$$

$$= \frac{(4\text{ M}L\text{D})(13\text{ mg}/L)(1{,}000{,}000)}{(642.3\text{ mg/m}L)(24\text{ hr/day})(60\text{ min/hr})(1\text{ Million})}$$

$$= 56\text{ m}L\text{/min}$$

EXAMPLE 7

A rectangular settling basin that is nine-meters long, five-meters wide, and two-meters deep treats a flow of 800 cubic meters per day. Estimate the detention time or settling time in hours in the basin for this flow.

Known	Unknown
Length, m = 9 m	Detention Time, hr
Width, m = 5 m	
Depth, m = 2 m	
Flow, cu m/day = 800 cu m/day	

1. Calculate the basin volume in cubic meters.

$$\text{Basin Volume, cu m} = (\text{Length, m})(\text{Width, m})(\text{Depth, m})$$

$$= (9\text{ m})(5\text{ m})(2\text{ m})$$

$$= 90\text{ cu m}$$

2. Calculate the detention time in hours.

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, cu m})(24\text{ hr/day})}{\text{Flow, cu m/day}}$$

$$= \frac{(90\text{ cu m})(24\text{ hr/day})}{800\text{ cu m/day}}$$

$$= 2.7\text{ hr}$$

EXAMPLE 8

Estimate the overflow rate in cubic meters per day per square meter of surface area for a seven-meter diameter clarifier that treats a flow of 300 cubic meters per day.

Known	Unknown
Diameter, m = 7 m	Overflow Rate, cu m/day/sq m
Flow, cu m/day = 300 cu m/day	

1. Calculate the surface area of the clarifier in square meters.
2. Surface Area, sq m = (0.785)(Diameter, m)^2

$$
\begin{aligned}
&= (0.785)(7\text{ m})^2\\
&= 38.5\text{ sq m}
\end{aligned}
$$

Determine the basin overflow rate in cubic meters per day per square meter of surface area.

$$
\begin{aligned}
\text{Overflow Rate, cu m/day/sq m} &= \frac{\text{Flow, cu m/day}}{\text{Surface Area, sq m}}\\
&= \frac{300\text{ cu m/day}}{38.5\text{ sq m}}\\
&= 7.8\text{ cu m/day/sq m}
\end{aligned}
$$

EXAMPLE 9

A seven-meter diameter circular clarifier treats a flow of 400 cubic meters per day. Calculate the weir loading in cubic meters per day per meter of weir length if the weir is on the outside edge of the clarifier.

Known	Unknown
Weir Diameter, m = 7 m	Weir Loading, cu m/day/m
Flow, cu m/day = 400 cu m/day	

1. Calculate the length of weir.

$$
\begin{aligned}
\text{Weir Length, m} &= \pi\,(\text{Weir Diameter, ft})\\
&= (3.14)(7\text{ m})\\
&= 22\text{ m}
\end{aligned}
$$

2. Estimate the weir loading in cubic meters per day per meter.

$$
\begin{aligned}
\text{Weir Loading, cu m/day/m} &= \frac{\text{Flow, cu m/day}}{\text{Weir Length, m}}\\
&= \frac{400\text{ cu m/day}}{22\text{ m}}\\
&= 18\text{ cu m/day/m of weir length}
\end{aligned}
$$

EXAMPLE 10

A five-meter wide by seven-meter long rapid sand filter treats a flow of 4000 cubic meters per day. Calculate the filtration rate in liters per second per square meter of filter surface area and also in millimeters per second.

Known	Unknown
Width, m = 5 m	1. Filtration Rate, *L*/sec/sq m
Length, m = 7 m	2. Filtration Rate, mm/sec
Flow, cu m/day = 4000 cu m/day	

1. Calculate the surface area of the filter.

$$
\begin{aligned}
\text{Surface Area, sq m} &= (\text{Length, m})(\text{Width, m})\\
&= (7\text{ m})(5\text{ m})\\
&= 35\text{ sq m}
\end{aligned}
$$

2. Convert the flow from cubic meters per day to liters per second.

$$
\begin{aligned}
\text{Flow, } L\text{/sec} &= \frac{(\text{Flow, cu m/day})(1000\ L\text{/cu m})}{(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}\\
&= \frac{(4000\text{ cu m/day})(1000\ L\text{/cu m})}{(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}\\
&= 46.3\ L\text{/sec}
\end{aligned}
$$

3. Determine the filtration rate in liters per second per square meter of filter surface area.

$$
\begin{aligned}
\text{Filtration Rate, } L\text{/sec/sq m} &= \frac{\text{Flow, liters/sec}}{\text{Surface Area, sq m}}\\
&= \frac{(46.3\ L\text{/sec})}{(35\text{ sq m})}\\
&= 1.32\ L\text{/sec/sq m}
\end{aligned}
$$

4. Calculate the filtration rate in millimeters per second.

$$
\begin{aligned}
\text{Filtration Rate, mm/sec} &= \frac{(\text{Flow, liters/sec})(1000\text{ mm/m})}{(\text{Surface Area, sq m})(1000\ L\text{/cu m})}\\
&= \frac{(46.3\ L\text{/sec})(1000\text{ mm/m})}{(35\text{ sq m})(1000\ L\text{/cu m})}\\
&= 1.32\text{ mm/sec}
\end{aligned}
$$

EXAMPLE 11

Calculate the backwash flow required in cubic meters per second to backwash a three-meter wide by five-meter long filter if the desired backwash flow rate is 15 liters per second per square meter.

Known		Unknown
Width, m	= 3 m	Backwash Flow, cu m/sec
Length, m	= 5 m	
Backwash Rate, *L*/sec/sq m	= 15 *L*/sec/sq m	

1. Calculate the surface area of the filter.

$$
\begin{aligned}
\text{Surface Area, sq m} &= (\text{Length, m})(\text{Width, m})\\
&= (5\text{ m})(3\text{ m})\\
&= 15\text{ sq m}
\end{aligned}
$$

2. Calculate the backwash flow in cubic meters per day.

$$
\begin{aligned}
\text{Backwash Flow, cu m/sec} &= \frac{(\text{Backwash Rate, } L\text{/sec/sq m})(\text{Area, sq m})}{1000\ L\text{/cu m}}\\
&= \frac{(15\ L\text{/sec/sq m})(15\text{ sq m})}{1000\ L\text{/cu m}}\\
&= 0.225\text{ cu m/sec}
\end{aligned}
$$

EXAMPLE 12

Estimate the ion exchange capacity in milligrams of hardness for a zeolite softener containing 5 cubic meters of media with a hardness removal capacity of 70 kilograms per cubic meter of media.

Known		Unknown
Media Vol, cu m	= 5 cu m	Ion Exchange Capacity, grams
Removal Capacity gm/cu m	= 70,000 gm/cu m	

Calculate the ion exchange capacity in grams of hardness.

$$\text{Ion Exchange Capacity, grams} = (\text{Media Vol, cu m})(\text{Removal Capacity, gm/cu m})$$

$$= (5\text{ cu m})(70{,}000\text{ gm/cu m})$$

$$= 350{,}000\text{ grams}$$

A.154 Disinfection

EXAMPLE 13

How many liters of five percent sodium hypochlorite will be needed to disinfect a well with a 0.5-meter diameter casing and well screen? The well is 60 meters deep and there is 25 meters of water in the well. Use an initial chlorine dose of 100 mg/*L*.

Known		Unknown
Hypochlorite, %	= 5%	5% Hypochlorite, *L*
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Diameter, m	= 0.5 m	
Well Depth, m	= 60 m	
Water Depth, m	= 25 m	

1. Calculate the volume of water in the well in liters.

$$\text{Water Vol, liters} = (0.785)(\text{Diameter, m})^2(\text{Depth, m})(1000\ L/\text{cu m})$$

$$= (0.785)(0.5\text{ m})^2(25\text{ m})(1000\ L/\text{cu m})$$

$$= 4906\text{ liters}$$

2. Determine the grams of chlorine needed.

$$\text{Chlorine, gm} = \frac{(\text{Volume, } L)(\text{Dose, mg}/L)}{1000\text{ mg/gm}}$$

$$= \frac{(4906\ L)(100\text{ mg}/L)}{1000\text{ mg/gm}}$$

$$= 491\text{ gm}$$

3. Calculate the liters of five percent sodium hypochlorite solution needed. One liter of water weighs 1000 grams.

$$\text{Sodium Hypochlorite Solution, liters} = \frac{(\text{Chlorine, gm})(100\%)}{(1000\text{ gm}/L)(\text{Hypochlorite, }\%)}$$

$$= \frac{(491\text{ gm})(100\%)}{(1000\text{ gm}/L)(5\%)}$$

$$= 9.8\text{ liters}$$

Ten liters should do the job.

4. *ALTERNATE SOLUTION*

Calculate the liters of five percent sodium hypochlorite solution needed. A five percent solution is the same as 50,000 mg per liter.

$$\text{Sodium Hypochlorite Solution, liters} = \frac{(\text{Volume, } L)(\text{Dose, mg}/L)}{\text{Hypochlorite Solution, mg}/L}$$

$$= \frac{(4906\ L)(100\text{ mg}/L)}{50{,}000\text{ mg}/L}$$

$$= 9.8\text{ liters}$$

EXAMPLE 14

A new 250-mm diameter water main 200-meters long needs to be disinfected. An initial chlorine dose of 400 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the three-hour disinfection period. How many liters of 5.25 percent (52,500 mg/*L*) sodium hypochlorite solution will be needed?

Known		Unknown
Diameter of Pipe, m	= 0.25 m	5.25% Hypochlorite, *L*
Length of Pipe, m	= 200 m	
Chlorine Dose, mg/*L*	= 400 mg/*L*	
Hypochlorite, %	= 5.25%	
Hypochlorite, mg/*L*	= 52,500 mg/*L*	

1. Calculate the volume of water in the pipe in liters.

$$\text{Pipe Vol, } L = (0.785)(\text{Diameter, m})^2(\text{Length, m})(1000\ L/\text{cu m})$$

$$= (0.785)(0.25\text{ m})^2(200\text{ m})(1000\ L/\text{cu m})$$

$$= 9813\ L$$

2. Calculate the liters of 5.25 percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, } L = \frac{(\text{Volume, } L)(\text{Dose, mg}/L)}{\text{Hypochlorite Solution, mg}/L}$$

$$= \frac{(9813\ L)(400\text{ mg}/L)}{52{,}500\text{ mg}/L}$$

$$= 75\text{ liters}$$

EXAMPLE 15

A service storage reservoir has been taken out of service for inspection, maintenance and repairs. The reservoir needs to be disinfected before being placed back on line. The reservoir is 12 meters in diameter and three-meters deep. An initial chlorine dose of 100 mg/*L* is expected to maintain a chlorine residual of over 50 mg/*L* during the 24-hour disinfection period. How many liters of 15 percent sodium hypochlorite solution will be needed?

Known		Unknown
Diameter, m	= 12 m	15% Hypochlorite, *L*
Tank Depth, m	= 3 m	
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Hypochlorite, %	= 15%	
Hypochlorite, mg/*L*	= 150,000 mg/*L*	

1. Calculate the volume of water in the tank in liters.

$$\text{Tank Volume, } L = (0.785)(\text{Diameter, m})^2(\text{Depth, m})(1000\ L/\text{cu m})$$

$$= (0.785)(12\text{ m})^2(3\text{ m})(1000\ L/\text{cu m})$$

$$= 339{,}120\ L$$

2. Calculate the liters of 15 percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, } L = \frac{(\text{Volume, } L)(\text{Dose, mg}/L)}{\text{Hypochlorite Solution, mg}/L}$$

$$= \frac{(339{,}120\ L)(100\text{ mg}/L)}{150{,}000\text{ mg}/L}$$

$$= 226\text{ liters}$$

EXAMPLE 16

Calculate the actual chlorine dose in milligrams per liter if 800 liters of a two percent sodium hypochlorite solution were used to treat eight megaliters of water.

Known	Unknown
Volume, Hypocl, *L* = 800 *L*	Chlorine Dose, mg/*L*
Volume Water, M*L* = 8 M*L*	
Hypochlorite, % = 2%	
Hypochlorite, mg/*L* = 20,000 mg/*L*	

Calculate the actual chlorine dose in milligrams per liter.

$$\text{Actual Dose, mg}/L = \frac{(\text{Hypochlorite, mg}/L)(\text{Volume Hypocl, }L)(1\text{ Million})}{(\text{Volume Water, M}L)(1{,}000{,}000)}$$

$$= \frac{(20{,}000\text{ mg}/L)(800\ L)(1\text{ Million})}{(8\text{ M}L)(1{,}000{,}000)}$$

$$= 2.0\text{ mg}/L$$

EXAMPLE 17

A deep-well turbine pump delivers 15 liters per second against typical operating heads. If the desired chlorine dose is 2.5 mg/*L*, what should be the chlorine feed rate in kilograms per day and milligrams per second.

Known	Unknown
Flow, *L*/sec = 15 *L*/sec	1. Chlorine Feed, kg/day
Dose, mg/*L* = 2.5 mg/*L*	2. Chlorine Feed, mg/sec

1. Calculate the chlorine feed in kilograms per day.

$$\text{Chlorine Feed, kg/day} = \frac{(\text{Flow, }L/\text{sec})(\text{Dose, mg}/L)(60\text{ sec/min})(60\text{ min/hr})(24\text{ hr/day})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}$$

$$= \frac{(15\ L/\text{sec})(2.5\text{ mg}/L)(60\text{ sec/min})(60\text{ min/hr})(24\text{ hr/day})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}$$

$$= 3.24\text{ kg/day}$$

2. Calculate the chlorine feed in milligrams per second.

$$\text{Chlorine Feed, mg/sec} = (\text{Flow, }L/\text{sec})(\text{Dose, mg}/L)$$

$$= (15\ L/\text{sec})(2.5\text{ mg}/L)$$

$$= 37.5\text{ mg/sec}$$

EXAMPLE 18

Estimate the chlorine demand for a water in milligrams per liter if the chlorine dose is 2.6 mg/*L* and the chlorine residual is 0.4 mg/*L*.

Known	Unknown
Chlorine, Dose, mg/*L* = 2.6 mg/*L*	Chlorine Demand, mg/*L*
Chlorine Residual, mg/*L* = 0.4 mg/*L*	

Estimate the chlorine demand in milligrams per liter.

$$\text{Chlorine Demand, mg}/L = \text{Chlorine Dose, mg}/L - \text{Chlorine Residual, mg}/L$$

$$= 2.6\text{ mg}/L - 0.4\text{ mg}/L$$

$$= 2.2\text{ mg}/L$$

EXAMPLE 19

Estimate the liters of hypochlorite pumped by a hypochlorinator if the hypochlorite solution is in a container with a diameter of one meter and the hypochlorite level drops 45 centimeters during a specific time period.

Known	Unknown
Diameter, m = 1 m	Hypochlorite Pumped, liters
Drop, cm = 45 cm	

Estimate the liters of hypochlorite pumped.

$$\text{Hypochlorite, liters} = (\text{Container Area, sq m})(\text{Drop, m})(1000\ L/\text{cu m})$$

$$= \frac{(0.785)(1\text{ m})^2(45\text{ cm})(1000\ L/\text{cu m})}{(100\text{ cm/m})}$$

$$= 353\text{ liters}$$

EXAMPLE 20

Estimate the desired strength (as a percent chlorine) of a hypochlorite solution which is pumped by a hypochlorinator that delivers 300 liters per day. The water being treated requires a chlorine dose of five kilograms of chlorine per day.

Known	Unknown
Hypochlorinator Flow, *L*/day = 300 *L*/day	Hypochlorite Strength, %
Chlorine Required, kg/day = 5 kg/day	

Estimate the desired hypochlorite strength as a percent chlorine.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, kg/day})(100\%)}{(\text{Hypochlorinator Flow, }L/\text{day})(1\text{ kg}/L)}$$

$$= \frac{(5\text{ kg/day})(100\%)}{(300\ L/\text{day})(1\text{ kg}/L)}$$

$$= 1.67\%$$

EXAMPLE 21

How many liters of water must be added to 40 liters of a five percent hypochlorite solution to produce a 1.67 percent hypochlorite solution:

Known	Unknown
Hypochlorite, *L* = 40 *L*	Water Added, *L*
Desired Hypo, % = 1.67%	
Actual Hypo, % = 5%	

Calculate the gallons of water that must be added to produce a 1.67 percent hypochlorite solution.

$$\text{Water Added, }L\text{ (to hypochlorite solution)} = \frac{(\text{Hypo, }L)(\text{Hypo, \%}) - (\text{Hypo, }L)(\text{Des Hypo, \%})}{\text{Desired Hypo, \%}}$$

$$= \frac{(40\ L)(5\%) - (40\ L)(1.67\%)}{1.67\%}$$

$$= \frac{200 - 66.8}{1.67}$$

$$= 80\text{ liters}$$

A.155 Laboratory Procedures

EXAMPLE 22

Convert a temperature of 77°F to degrees Celsius.

Known	Unknown
Temp, °F = 77°F	Temp, °C

Change 77°F to degrees Celsius.

$$\text{Temperature, °C} = \frac{5(\text{°F} - 32\text{°F})}{9}$$

$$= \frac{5(77\text{°F} - 32\text{°F})}{9}$$

$$= 25\text{°C}$$

EXAMPLE 23

Convert a temperature of 15°C to degrees Fahrenheit.

Known	Unknown
Temp, °C = 15°C	Temp, °F

Change 15°C to degrees Fahrenheit.

$$\text{Temperature, °C} = \frac{9(\text{°C})}{5} + 32\text{°F}$$

$$= \frac{9(15\text{°C})}{5} + 32\text{°F}$$

$$= 59\text{°F}$$

WATER ABBREVIATIONS

ac	acre
ac-ft	acre-feet
af	acre feet
amp	ampere
°C	degrees Celsius
cfm	cubic feet per minute
cfs	cubic feet per second
Ci	Curie
cm	centimeter
cu ft	cubic feet
cu in	cubic inch
cu m	cubic meter
cu yd	cubic yard
°F	degrees Fahrenheit
ft	feet or foot
ft-lb/min	foot-pounds per minute
g	gravity
gal	gallon
gal/day	gallons per day
gm	gram
GPD	gallons per day
GPM	gallons per minute
gpg	grains per gallon
gr	grain
ha	hectare
HP	horsepower
hr	hour
in	inch
k	kilo
kg	kilogram
km	kilometer
kN	kilonewton
kW	kilowatt
kWh	kilowatt-hour
L	liter
lb	pound
lbs/sq in	pounds per square inch
m	meter
M	mega
M	million
mg	milligram
mg/*L*	milligram per liter
MGD	million gallons per day
m*L*	milliliter
min	minute
mm	millimeter
N	Newton
ohm	ohm
Pa	Pascal
pCi	picoCurie
psf	pounds per square foot
psi	pounds per square inch
psig	pounds per square inch gage
ppb	parts per billion
ppm	parts per million
sec	second
sq ft	square feet
sq in	square inches
W	watt

WATER WORDS

A Summary of the Words Defined

in

WATER TREATMENT PLANT OPERATION

WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE

and

SMALL WATER SYSTEM OPERATION AND MAINTENANCE

PROJECT PRONUNCIATION KEY

by Warren L. Prentice

The Project Pronunciation Key is designed to aid you in the pronunciation of new words. While this Key is based primarily on familiar sounds, it does not attempt to follow any particular pronunciation guide. This Key is designed solely to aid operators in this program.

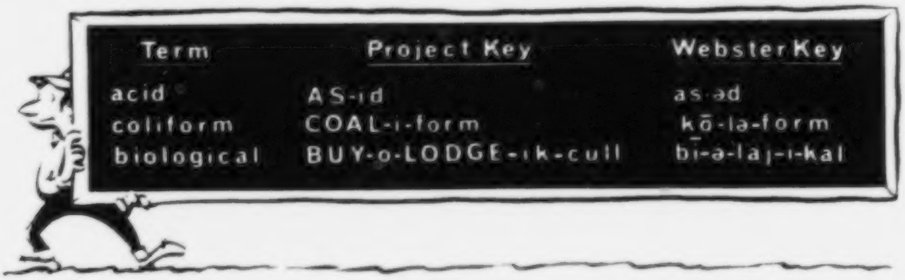
You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation Key. Each Key will be different from each other and from this Key. Examples of the differences between the Key used in this program and the *WEBSTER'S NEW WORLD DICTIONARY* "Key[1]", are shown below.

In using this Key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	SYLLABLE				
Word	1st	2nd	3rd	4th	5th
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word *ACID* has its first syllable accented. The second word, *COAGULANT*, has its second syllable accented. The third word, *BIOLOGICAL*, has its first and third syllables accented.

We hope you will find the Key useful in unlocking the pronunciation of any new word.



Term	Project Key	Webster Key
acid	AS-id	as·əd
coliform	COAL-i-form	kō-la-form
biological	BUY-o-LODGE-ik-cull	bī-ə-laj-i-kal

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[1] The WEBSTER'S NEW WORLD DICTIONARY, *Second College Edition, 1972, was chosen rather than an unabridged dictionary because of its availability to the operator. Other editions may be slightly different.*

WATER WORDS

ABC ABC

See **A**ssociation of **B**OARDS of **C**ertification

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ACCURACY ACCURACY

How closely an instrument measures the true or actual value of the process variable being measured or sensed.

ACID RAIN ACID RAIN

Precipitation which has been rendered (made) acidic by airborne pollutants.

ACIDIC (uh-SID-ick) ACIDIC

The condition of water or soil which contains a sufficient amount of acid substances to lower the pH below 7.0.

ACIDIFIED (uh-SID-uh-FIE-d) ACIDIFIED

The addition of an acid (usually nitric or sulfuric) to a sample to lower the pH below 2.0. The purpose of acidification is to "fix" a sample so it won't change until it is analyzed.

ACRE-FOOT ACRE-FOOT

A volume of water that covers one acre to a depth of one foot, or 43,560 cubic feet (1233.5 cubic meters).

ACTIVATED CARBON ACTIVATED CARBON

Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble materials from water.

ACUTE ACUTE

Effects of an exposure which causes severe symptoms to occur quickly.

ADSORBATE (add-SORE-bait) ADSORBATE

The material being removed by the adsorption process.

ADSORBENT (add-SORE-bent) ADSORBENT

The material (activated carbon) that is responsible for removing the undesirable substance in the adsorption process.

ADSORPTION (add-SORP-shun) ADSORPTION

The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AERATION (air-A-shun) AERATION

The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.

AEROBIC (air-O-bick) AEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is present in the water.

AESTHETIC (es-THET-ick) AESTHETIC

Attractive or appealing.

AGE TANK AGE TANK

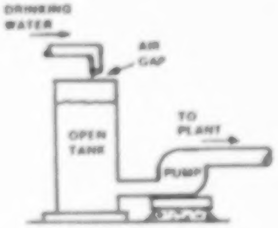
A tank used to store a chemical solution of known concentration for feed to a chemical feeder. Also called a DAY TANK.

AIR BINDING AIR BINDING

A situation where air enters the filter media. Air is harmful to both the filtration and backwash processes. Air can prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.

AIR GAP AIR GAP

An open vertical drop, or vertical empty space, that separates a drinking (potable) water supply to be protected from another water system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because there is no way raw water or any other water can reach the drinking water.



AIR PADDING AIR PADDING

Pumping dry air into a container to assist with the withdrawal of a liquid or to force a liquefied gas such as chlorine out of a container.

AIR STRIPPING AIR STRIPPING

A treatment process used to remove dissolved gases and volatile substances from water. Large volumes of air are bubbled through the water being treated to remove (strip out) the dissolved gases and volatile substances.

ALARM CONTACT ALARM CONTACT

A switch that operates when some pre-set low, high or abnormal condition exists.

ALGAE (Al-gee) ALGAE

Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciably affect the pH and dissolved oxygen of the water.

ALGAL BLOOM (AL-gull) ALGAL BLOOM

Sudden, massive growths of microscopic and macroscopic plant life, such as green or blue-green algae, which develop in lakes and reservoirs.

ALGICIDE (AL-gi-SIDE) ALGICIDE

Any substance or chemical specifically formulated to kill or control algae.

ALIPHATIC HYDROXY ACIDS (AL-uh-FAT-ick) ALIPHATIC HYDROXY ACIDS

Organic acids with carbon atoms arranged in branched or unbranched open chains rather than in rings.

ALIQUOT (AL-li-kwot) ALIQUOT

Portion of a sample.

ALKALI (AL-ka-lie) ALKALI

Various soluble salts, principally of sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical water treatment processes.

ALKALINE (AL-ka-LINE) ALKALINE

The condition of water or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

ALKALINITY (AL-ka-LIN-it-tee) ALKALINITY

The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

ALLUVIAL (uh-LOU-vee-ul) ALLUVIAL

Relating to mud and/or sand deposited by flowing water. Alluvial deposits may occur after a heavy rain storm.

ALTERNATING CURRENT (A.C.) ALTERNATING CURRENT (A.C.)

An electric current that reverses its direction (positive/negative values) at regular intervals.

ALTITUDE VALVE **ALTITUDE VALVE**

A valve that automatically shuts off the flow into an elevated tank when the water level in the tank reaches a predetermined level. The valve automatically opens when the pressure in the distribution system drops below the pressure in the tank.

AMBIENT TEMPERATURE (AM-bee-ent) **AMBIENT TEMPERATURE**

Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

AMERICAN WATER WORKS ASSOCIATION **AMERICAN WATER WORKS ASSOCIATION**

A professional organization for all persons working in the water utility field. For information on AWWA membership and publications, contact AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235.

AMPERAGE (AM-purr-age) **AMPERAGE**

The strength of an electric current measured in amperes. The amount of electric current flow, similar to the flow of water in gallons per minute.

AMPERE (AM-peer) **AMPERE**

The unit used to measure current strength. The current produced by an electromotive force of one volt acting through a resistance of one ohm.

AMPEROMETRIC (am-PURR-o-MET-rick) **AMPEROMETRIC**

Based on the electric current that flows between two electrodes in a solution.

AMPEROMETRIC TITRATION **AMPEROMETRIC TITRATION**

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction. See TITRATE.

ANAEROBIC (AN-air-O-bick) **ANAEROBIC**

A condition in which "free" (atmospheric) or dissolved oxygen is *NOT* present in water.

ANALOG **ANALOG**

The readout of an instrument by a pointer (or other indicating means) against a dial or scale.

ANALYZER **ANALYZER**

A device which conducts periodic or continuous measurement of some factor such as chlorine, fluoride or turbidity. Analyzers operate by any of several methods including photocells, conductivity or complex instrumentation.

ANION (AN-EYE-en) **ANION**

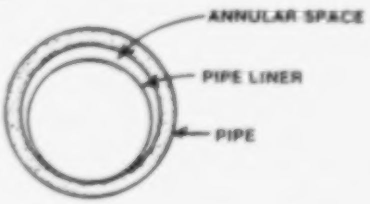
A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of a difference in electrical potential. Chloride (Cl^-) is an anion.

ANIONIC POLYMER (AN-eye-ON-ick) **ANIONIC POLYMER**

A polymer having negatively charged groups of ions; often used as a filter aid and for dewatering sludges.

ANNULAR SPACE (AN-you-ler) **ANNULAR SPACE**

A ring-shaped space located between two circular objects, such as two pipes.



ANODE (an-O-d) **ANODE**

The positive pole or electrode of an electrolytic system, such as a battery. The anode attracts negatively charged particles or ions (anions).

APPROPRIATIVE **APPROPRIATIVE**

Water rights to or ownership of a water supply which is acquired for the beneficial use of water by following a specific legal procedure.

APPURTENANCE (uh-PURR-ten-nans) APPURTENANCE

Machinery, appliances, structures and other parts of the main structure necessary to allow it to operate as intended, but not considered part of the main structure.

AQUEOUS (A-kwee-us) AQUEOUS

Something made up of, similar to, or containing water; watery.

AQUIFER (ACK-wi-fer) AQUIFER

A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

ARTESIAN (are-TEE-zhun) ARTESIAN

Pertaining to groundwater, a well, or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given an opportunity to do so.

ASEPTIC (a-SEP-tick) ASEPTIC

Free from the living germs of disease, fermentation or putrefaction. Sterile.

ASSOCIATION OF BOARDS OF CERTIFICATION ASSOCIATION OF BOARDS OF CERTIFICATION

An international organization representing over seventy boards which certify the operators of waterworks and wastewater facilities. For information on ABC publications regarding the preparation of and how to study for operator certification examinations, contact ABC, P.O. Box 2266, Ames, Iowa 50010.

ASYMMETRIC (A-see-MET-rick) ASYMMETRIC

Not similar in size, shape, form or arrangement of parts on opposite sides of a line, point or plane.

ATOM ATOM

The smallest unit of a chemical element; composed of protons, neutrons and electrons.

AUDIT, WATER AUDIT, WATER

A thorough examination of the accuracy of water agency records or accounts (volumes of water) and system control equipment. Water managers can use audits to determine their water distribution system efficiency. The overall goal is to identify and verify water and revenue losses in a water system.

AVAILABLE CHLORINE AVAILABLE CHLORINE

A measure of the amount of chlorine available in chlorinated lime, hypochlorite compounds, and other materials that are used as a source of chlorine when compared with that of elemental (liquid or gaseous) chlorine.

AVAILABLE EXPANSION AVAILABLE EXPANSION

The vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called FREEBOARD.

AVERAGE AVERAGE

A number obtained by adding quantities or measurements and dividing the sum or total by the number of quantities or measurements. Also called the ARITHMETIC MEAN.

$$\text{Average} = \frac{\text{Sum of Measurements}}{\text{Number of Measurements}}$$

AVERAGE DEMAND AVERAGE DEMAND

The total demand for water during a period of time divided by the number of days in that time period. This is also called the AVERAGE DAILY DEMAND.

AWWA AWWA

See AMERICAN WATER WORKS ASSOCIATION.

AXIAL TO IMPELLER AXIAL TO IMPELLER

The direction in which material being pumped flows around the impeller or flow parallel to the impeller shaft.

AXIS OF IMPELLER AXIS OF IMPELLER

An imaginary line running along the center of a shaft (such as an impeller shaft).

BACK PRESSURE BACK PRESSURE

A pressure that can cause water to backflow into the water supply when a user's water system is at a higher pressure than the public water system.

BACKFLOW BACKFLOW

A reverse flow condition, created by a difference in water pressures, which causes water to flow back into the distribution pipes of a potable water supply from any source or sources other than an intended source. Also see BACKSIPHONAGE.

BACKSIPHONAGE BACKSIPHONAGE

A form of backflow caused by a negative or below atmospheric pressure within a water system. Also see BACKFLOW.

BACKWASHING BACKWASHING

The process of reversing the flow of water back through the filter media to remove the entrapped solids.

BACTERIA (back-TEER-e-uh) BACTERIA

Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BAFFLE BAFFLE

A flat board or plate, deflector, guide or similar device constructed or placed in flowing water or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids (water, chemical solutions, slurry).

BAILER (BAY-ler) BAILER

A 10- to 20-foot-long pipe equipped with a valve at the lower end. A bailer is used to remove slurry from the bottom or the side of a well as it is being drilled.

BASE METAL BASE METAL

A metal (such as iron) which reacts with dilute hydrochloric acid to form hydrogen. Also see NOBLE METAL.

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reactor is filled, the water is treated or a chemical solution is prepared, and the tank is emptied. The tank may then be filled and the process repeated.

BIOCHEMICAL OXYGEN DEMAND BIOCHEMICAL OXYGEN DEMAND

BOD. The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

BIOLOGICAL GROWTH BIOLOGICAL GROWTH

The activity and growth of any and all living organisms.

BLANK BLANK

A bottle containing only dilution water or distilled water; the sample being tested is not added. Tests are frequently run on a SAMPLE and a BLANK and the differences are compared.

BOD (pronounce as separate letters) BOD

Biochemical **O**xygen **D**emand. The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

BONNET (BON-it) BONNET

The cover on a gate valve.

BOWLS, PUMP BOWLS, PUMP

The submerged pumping unit in a well, including the shaft, impellers and housing.

BRAKE HORSEPOWER BRAKE HORSEPOWER

(1) The horsepower required at the top or end of a pump shaft (input to a pump).

(2) The energy provided by a motor or other power source.

BREAKPOINT CHLORINATION BREAKPOINT CHLORINATION

Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

BREAKTHROUGH BREAKTHROUGH

A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter. This will cause an increase in filter effluent turbidity. A breakthrough can occur (1) when a filter is first placed in service, (2) when the effluent valve suddenly opens or closes, and (3) during periods of excessive head loss through the filter (including when the filter is exposed to negative heads).

BRINELLING (bruh-NEL-ing) BRINELLING

Tiny indentations (dents) high on the shoulder of the bearing race or bearing. A type of bearing failure.

BUFFER BUFFER

A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.

BUFFER CAPACITY BUFFER CAPACITY

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.

C FACTOR C FACTOR

A factor or value used to indicate the smoothness of the interior of a pipe. The higher the C Factor, the smoother the pipe, the greater the carrying capacity, and the smaller the friction or energy losses from water flowing in the pipe. To calculate the C Factor, measure the flow, pipe diameter, distance between two pressure gages, and the friction or energy loss of the water between the gages.

$$\text{C Factor} = \frac{\text{Flow, GPM}}{193.75\ (\text{Diameter, ft})^{2.63}\ (\text{Slope})^{0.54}}$$

CAISSON (KAY-sawn) CAISSON

A structure or chamber which is usually sunk or lowered by digging from the inside. Used to gain access to the bottom of a stream or other body of water.

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT

An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

CALIBRATION CALIBRATION

A procedure which checks or adjusts an instrument's accuracy by comparison with a standard or reference.

CAPILLARY ACTION CAPILLARY ACTION

The movement of water through very small spaces due to molecular forces.

CAPILLARY FORCES CAPILLARY FORCES

The molecular forces which cause the movement of water through very small spaces.

CAPILLARY FRINGE CAPILLARY FRINGE

The porous material just above the water table which may hold water by capillarity (a property of surface tension that draws water upwards) in the smaller void spaces.

CARCINOGEN (car-SIN-o-jen) CARCINOGEN

Any substance which tends to produce cancer in an organism.

CATALYST (CAT-uh-LIST) CATALYST

A substance that changes the speed or yield of a chemical reaction without being consumed or chemically changed by the chemical reaction.

CATALYZE (CAT-uh-LIZE) CATALYZE

To act as a catalyst. Or, to speed up a chemical reaction.

CATALYZED (CAT-uh-LIZED) CATALYZED

To be acted upon by a catalyst.

CATHODE (KA-thow-d) CATHODE

The negative pole or electrode of an electrolytic cell or system. The cathode attracts positively charged particles or ions (cations).

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

An electrical system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic. This concentrates corrosion on auxiliary anodic parts which are deliberately allowed to corrode instead of letting the structure corrode.

CATION (CAT-EYE-en)
CATION

A positively charged ion in an electrolyte solution, attracted to the cathode under the influence of a difference in electrical potential. Sodium ion (Na^+) is a cation.

CATIONIC POLYMER
CATIONIC POLYMER

A polymer having positively charged groups of ions; often used as a coagulant aid.

CAVITATION (CAV-uh-TAY-shun)
CAVITATION

The formation and collapse of a gas pocket or bubble on the blade of an impeller or the gate of a valve. The collapse of this gas pocket or bubble drives water into the impeller or gate with a terrific force that can cause pitting on the impeller or gate surface. Cavitation is accompanied by loud noises that sound like someone is pounding on the impeller or gate with a hammer.

CENTRATE
CENTRATE

The water leaving a centifuge after most of the solids have been removed.

CENTRIFUGAL PUMP (sen-TRIF-uh-gull)
CENTRIFUGAL PUMP

A pump consisting of an impeller fixed on a rotating shaft that is enclosed in a casing, and having an inlet and discharge connection. As the rotating impeller whirls the water around, centrifugal force builds up enough pressure to force the water through the discharge outlet.

CENTRIFUGE
CENTRIFUGE

A mechanical device that uses centrifugal or rotational forces to separate solids from liquids.

CHECK VALVE
CHECK VALVE

A special valve with a hinged disc or flap that opens in the direction of normal flow and is forced shut when flows attempt to go in the reverse or opposite direction of normal flow.

CHELATION (key-LAY-shun)
CHELATION

A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds, such as EDTA (ethylene diamine tetracetic acid). Chelation is used to prevent the precipitation of metals (copper). Also see SEQUESTRATION.

CHLORAMINES (KLOR-uh-means)
CHLORAMINES

Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

CHLORINATION (KLOR-uh-NAY-shun)
CHLORINATION

The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results (aiding coagulation and controlling tastes and odors).

CHLORINATOR (KLOR-uh-NAY-ter)
CHLORINATOR

A metering device which is used to add chlorine to water.

CHLORINE DEMAND
CHLORINE DEMAND

Chlorine demand is the difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

$$\text{Chlorine Demand, mg/}L = \underset{\text{Applied, mg/}L}{\text{Chlorine}} - \underset{\text{Residual, mg/}L}{\text{Chlorine}}$$

CHLORINE REQUIREMENT
CHLORINE REQUIREMENT

The amount of chlorine which is needed for a particular purpose. Some reasons for adding chlorine are reducing the number of coliform bacteria (Most Probable Number), obtaining a particular chlorine residual, or oxidizing some substance in the water. In each case a definite dosage of chlorine will be necessary. This dosage is the chlorine requirement.

CHLOROPHENOLIC (klor-o-FEE-NO-lick)
CHLOROPHENOLIC

Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.

CHLOROPHENOXY (KLOR-o-fuh-KNOX-ee)
CHLOROPHENOXY

A class of herbicides that may be found in domestic water supplies and cause adverse health effects. Two widely used chlorophenoxy herbicides are 2,4-D (2,4-Dichlorophenoxy acetic acid) and 2,4,5-TP (2,4,5-Trichlorophenoxy propionic acid (silvex)).

CHLORORGANIC (klor-or-GAN-nick) CHLORORGANIC

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.

CHRONIC CHRONIC

Effects of an exposure which causes symptoms to continue for a long time.

CIRCLE OF INFLUENCE CIRCLE OF INFLUENCE

The circular outer edge of a depression produced in the water table by the pumping of water from a well. Also see CONE OF INFLUENCE and CONE OF DEPRESSION.

[SEE DRAWING ON PAGE 480]

CIRCUIT CIRCUIT

The complete path of an electric current, including the generating apparatus or other source; or, a specific segment or section of the complete path.

CIRCUIT BREAKER CIRCUIT BREAKER

A safety device in an electrical circuit that automatically shuts off the circuit when it becomes overloaded. The device can be manually reset.

CISTERN (SIS-turn) CISTERN

A small tank (usually covered) or a storage facility used to store water for a home or farm. Often used to store rain water.

CLARIFIER (KLAIR-uh-fire) CLARIFIER

A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom. Clarifiers are also called SETTLING BASINS and SEDIMENTATION BASINS.

CLASS, PIPE AND FITTINGS CLASS, PIPE AND FITTINGS

The working pressure rating of a specific pipe for use in water distribution systems which includes allowances for surges. The term is used for cast iron, ductile iron, asbestos cement and some plastic pipe.

CLEAR WELL CLEAR WELL

A reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand. Also used to provide chlorine contact time for disinfection.

COAGULANT AID COAGULANT AID

Any chemical or substance used to assist or modify coagulation.

COAGULANTS (co-AGG-you-lents) COAGULANTS

Chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the water by settling, skimming, draining or filtering.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The clumping together of very fine particles into larger particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

COLIFORM (COAL-i-form) COLIFORM

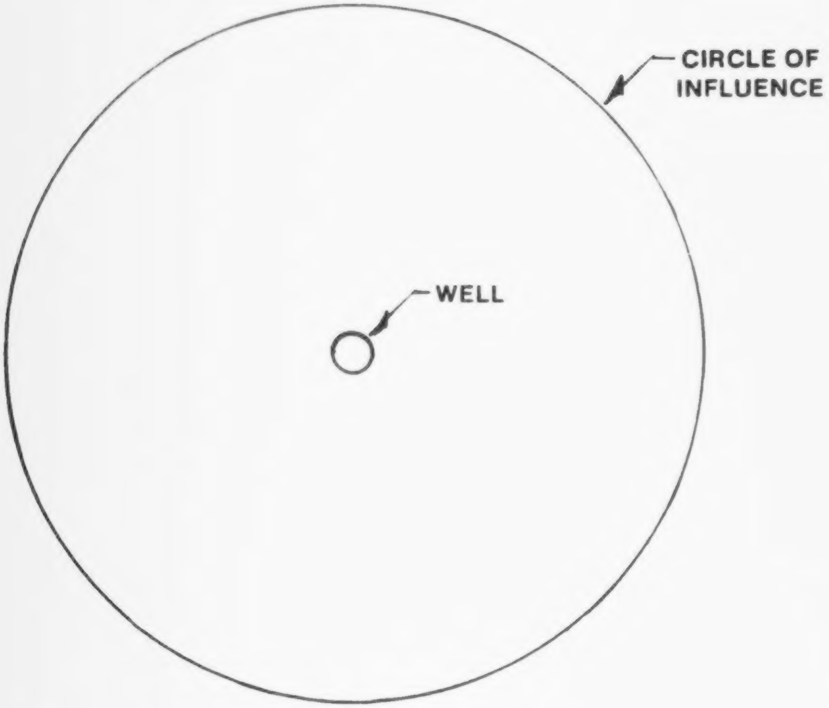
A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhibit the intestines of warm-blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.

COLLOIDS (CALL-loids) COLLOIDS

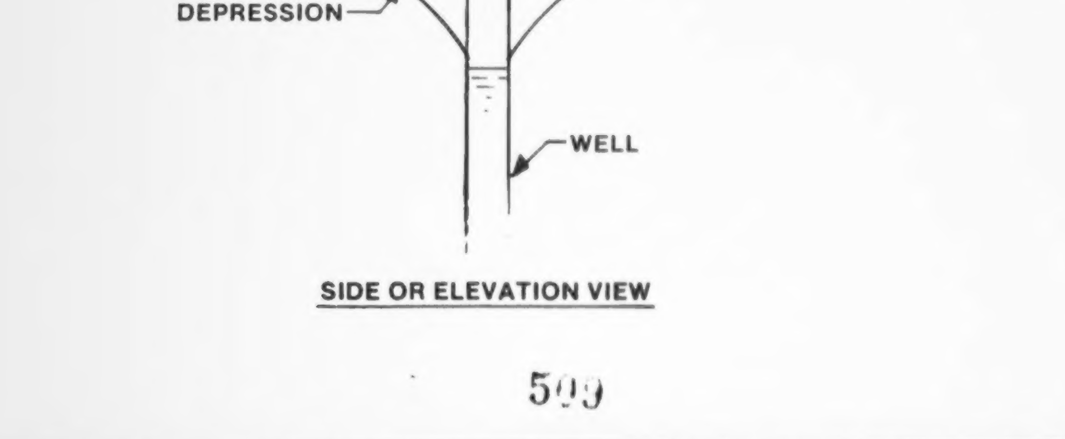
Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.


CIRCLE OF INFLUENCE
WELL

TOP OR PLAN VIEW


GROUND SURFACE
ORIGINAL WATER LEVEL
CIRCLE OF INFLUENCE
CONE OF DEPRESSION
WELL

SIDE OR ELEVATION VIEW

COMBINED AVAILABLE RESIDUAL CHLORINE COMBINED AVAILABLE RESIDUAL CHLORINE

The concentration of residual chlorine which is combined with ammonia (NH_3) and/or organic nitrogen in water as a chloramine (or other chloro derivative) yet is still available to oxidize organic matter and utilize its bactericidal properties.

COMBINED RESIDUAL CHLORINATION COMBINED RESIDUAL CHLORINATION

The application of chlorine to water to produce combined available residual chlorine. This residual can be made up of monochloramines, dichloramines, and nitrogen trichloride.

COMPLETE TREATMENT COMPLETE TREATMENT

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called CONVENTIONAL FILTRATION.

COMPOSITE (come-PAH-zit) (PROPORTIONAL) SAMPLES COMPOSITE (PROPORTIONAL) SAMPLES

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

COMPOUND COMPOUND

A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride-NaCl) is a compound.

CONCENTRATION POLARIZATION CONCENTRATION POLARIZATION

(1) The ratio of the salt concentration in the membrane boundary layer to the salt concentration in the bulk stream. The most common and serious problem resulting from concentration polarization is the increasing tendency for precipitation of sparingly soluble salts and the deposition of particulate matter on the membrane surface.

(2) Used in corrosion studies to indicate a depletion of ions near an electrode.

(3) The basis for chemical analysis by a polarograph.

CONDUCTANCE CONDUCTANCE

A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called SPECIFIC CONDUCTANCE.

CONDUCTIVITY CONDUCTIVITY

A measure of the ability of a solution (water) to carry an electric current.

CONDUCTOR CONDUCTOR

A substance, body, device or wire that readily conducts or carries electrical current.

CONDUCTOR CASING CONDUCTOR CASING

The outer casing of a well. The purpose of this casing is to prevent contaminants from surface waters or shallow groundwaters from entering a well.

CONE OF DEPRESSION CONE OF DEPRESSION

The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF INFLUENCE.

[SEE DRAWING ON PAGE 480]

CONE OF INFLUENCE CONE OF INFLUENCE

The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF DEPRESSION.

[SEE DRAWING ON PAGE 480]

CONFINED SPACE* CONFINED SPACE

A space defined by the concurrent existence of the following conditions:

A. Existing ventilation is insufficient to remove dangerous air contamination and/or oxygen deficiency which may exist or develop, and

B. Ready access or egress (getting out) for the removal of a suddenly disabled employee (operator) is difficult due to the location and/or size of the opening(s).

Also see definitions of *DANGEROUS AIR CONTAMINATION* and *DEFICIENCY*.

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* *CONFINED SPACES, General Industry Safety Orders, Article 108, Title 8, California Administrative Code, Cal/OSHA Consultation Service, Sacramento, California, October, 1980.*

CONSOLIDATED FORMATION CONSOLIDATED FORMATION

A geologic material whose particles are stratified (layered), cemented or firmly packed together (hard rock); usually occurring at a depth below the ground surface. Also see UNCONSOLIDATED FORMATION.

CONTACTOR CONTACTOR

An electrical switch, usually magnetically operated.

CONTAMINATION CONTAMINATION

The introduction into water of microorganisms, chemicals, toxic substances, wastes, or wastewater in a concentration that makes the water unfit for its next intended use.

CONTINUOUS SAMPLE CONTINUOUS SAMPLE

A flow of water from a particular place in a plant to the location where samples are collected for testing. This continuous stream may be used to obtain grab or composite samples. Frequently, several taps (faucets) will flow continuously in the laboratory to provide test samples from various places in a water treatment plant.

CONTROL LOOP CONTROL LOOP

The path through the control system between the sensor, which measures a process variable, and the controller, which controls or adjusts the process variable.

CONTROL SYSTEM CONTROL SYSTEM

A system which senses and controls its own operation on a close, continuous basis in what is called proportional (or modulating) control.

CONTROLLER CONTROLLER

A device which controls the starting, stopping, or operation of a device or piece of equipment.

CONVENTIONAL FILTRATION CONVENTIONAL FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called COMPLETE TREATMENT. Also see DIRECT FILTRATION and IN-LINE FILTRATION.

CONVENTIONAL TREATMENT CONVENTIONAL TREATMENT

See CONVENTIONAL FILTRATION. Also called COMPLETE TREATMENT.

CORPORATION STOP CORPORATION STOP

A water service shutoff valve located at a street water main. This valve cannot be operated from the ground surface because it is buried and there is no valve box. Also called a CORPORATION COCK.

CORROSION CORROSION

The gradual decomposition or destruction of a material by chemical action, often due to an electrochemical reaction. Corrosion may be caused by (1) stray current electrolysis, (2) galvanic corrosion caused by dissimilar metals, or (3) differential-concentration cells. Corrosion starts at the surface of a material and moves inward.

CORROSION INHIBITORS CORROSION INHIBITORS

Substances that slow the rate of corrosion.

CORROSIVITY CORROSIVITY

An indication of the corrosiveness of a water. The corrosiveness of a water is described by the water's pH, alkalinity, hardness, temperature, total dissolved solids, dissolved oxygen concentration, and the Langelier Index.

COULOMB (COO-lahm) COULOMB

A measurement of the amount of electrical charge conveyed by an electric current of one ampere in one second. One coulomb equals about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons).

COUPON COUPON

A steel specimen inserted into water to measure the corrosiveness of water. The rate of corrosion is measured as the loss of weight of the coupon (in milligrams) per surface area (in square decimeters) exposed to the water per day.

10 decimeters = 1 meter = 100 centimeters

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

CURB STOP CURB STOP

A water service shutoff valve located in a water service pipe near the curb and between the water main and the building. This valve is usually operated by a wrench or valve key and is used to start or stop flows in the water service line to a building. Also called a "curb cock."

CURIE CURIE

A measure of radioactivity. One Curie of radioactivity is equivalent to 3.7×10^{10} or 37,000,000,000 nuclear disintegrations per second.

CURRENT CURRENT

A movement or flow of electricity. Water flowing in a pipe is measured in gallons per second past a certain point, not by the number of water molecules going past a point. Electric current is measured by the number of coulombs per second flowing past a certain point in a conductor. A coulomb is equal to about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons). A flow of one coulomb per second is called one ampere, the unit of the rate of flow of current.

DANGEROUS AIR CONTAMINATION DANGEROUS AIR CONTAMINATION

An atmosphere presenting a threat of causing death, injury, acute illness, or disablement due to the presence of flammable and/or explosive, toxic or otherwise injurious or incapacitating substances.

A. Dangerous air contamination due to the flammability of a gas or vapor is defined as an atmosphere containing the gas or vapor at a concentration greater than 20 percent of its lower explosive (lower flammable) limit.

B. Dangerous air contamination due to a combustible particulate is defined as a concentration greater than 20 percent of the minimum explosive concentration of the particulate.

C. Dangerous air contamination due to the toxicity of a substance is defined as the atmospheric concentration immediately hazardous to life or health.

DATEOMETER (day-TOM-uh-ter) DATEOMETER

A small calendar disc attached to motors and equipment to indicate the year in which the last maintenance service was performed.

DATUM LINE DATUM LINE

A line from which heights and depths are calculated or measured. Also called a DATUM PLANE or a DATUM LEVEL.

DAY TANK DAY TANK

A tank used to store a chemical solution of known concentration for feed to a chemical feeder. A day tank usually stores sufficient chemical solution to properly treat the water being treated for at least one day. Also called an AGE TANK.

DEAD END DEAD END

The end of a water main which is not connected to other parts of the distribution system by means of a connecting loop of pipe.

DECANT DECANT

To draw off the upper layer of liquid (water) after the heavier material (a solid or another liquid) has settled.

DECHLORINATION (dee-KLOR-uh-NAY-shun) DECHLORINATION

The deliberate removal of chlorine from water. The partial or complete reduction of residual chlorine by any chemical or physical process.

DECIBEL (DES-uh-bull) DECIBEL

A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average level at which sound causes pain to humans.

DECOMPOSITION DECOMPOSITION

The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odors are produced. Decay of organic matter when oxygen is present (aerobic conditions) tends to produce much less objectionable tastes and odors.

DEFLUORIDATION (de-FLOOR-uh-DAY-shun) DEFLUORIDATION

The removal of excess fluoride in drinking water to prevent the mottling (brown stains) of teeth.

DEGASIFICATION (DEE-GAS-if-uh-KAY-shun) DEGASIFICATION

A water treatment process which removes dissolved gases from the water. The gases may be removed by either mechanical or chemical treatment methods or a combination of both.

DEMINERALIZATION (DEE-MIN-er-al-uh-ZAY-shun) DEMINERALIZATION

A treatment process which removes dissolved minerals (salts) from water.

DENSITY (DEN-sit-tee) DENSITY

A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic feet. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

DESALINIZATION (DEE-SAY-leen-uh-ZAY-shun) DESALINIZATION

The removal of dissolved salts (such as sodium chloride, NaCl) from water by natural means (leaching) or by specific water treatment processes.

DESICCANT (DESS-uh-kant) DESICCANT

A drying agent which is capable of removing or absorbing moisture from the atmosphere in a small enclosure.

DESICCATION (DESS-uh-KAY-shun) DESICCATION

A process used to thoroughly dry air; to remove virtually all moisture from air.

DESICCATOR (DESS-uh-KAY-tor) DESICCATOR

A closed container into which heated weighing or drying dishes are placed to cool in a dry environment. The dishes may be empty or they may contain a sample. Desiccators contain a substance, such as anhydrous calcium chloride, which absorbs moisture and keeps the relative humidity near zero so that the dish or sample will not gain weight from absorbed moisture.

DESTRATIFICATION (de-STRAT-uh-fuh-KAY-shun) DESTRATIFICATION

The development of vertical mixing within a lake or reservoir to eliminate (either totally or partially) separate layers of temperature, plant, or animal life. This vertical mixing can be caused by mechanical means (pumps) or through the use of forced air diffusers which release air into the lower layers of the reservoir.

DETECTION LAG DETECTION LAG

The time period between the moment a change is made and the moment when such a change is finally sensed by the associated measuring instrument.

DETENTION TIME DETENTION TIME

(1) The theoretical (calculated) time required for a small amount of water to pass through a tank at a given rate of flow.

(2) The actual time in hours, minutes or seconds that a small amount of water is in a settling basin, flocculating basin or rapid-mix chamber. In storage reservoirs, detention time is the length of time entering water will be held before being drafted for use (several weeks to years, several months being typical).

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

DEW POINT DEW POINT

The temperature to which air with a given quantity of water vapor must be cooled to cause condensation of the vapor in the air.

DEWATER DEWATER

(1) To remove or separate a portion of the water present in a sludge or slurry. To dry sludge so it can be handled and disposed of.

(2) To remove or drain the water from a tank or a trench.

DIATOMACEOUS EARTH (DYE-uh-toe-MAY-shus) DIATOMACEOUS EARTH

A fine, siliceous (made of silica) "earth" composed mainly of the skeletal remains of diatoms.

DIATOMS (DYE-uh-toms) DIATOMS

Unicellular (single cell), microscopic algae with a rigid (box-like) internal structure consisting mainly of silica.

DIGITAL READOUT DIGITAL READOUT

Use of numbers to indicate the value or measurement of a variable. The readout of an instrument by a direct, numerical reading of the measured value.

DILUTE SOLUTION DILUTE SOLUTION

A solution that has been made weaker usually by the addition of water.

DIMICTIC (die-MICK-tick) DIMICTIC

Lakes and reservoirs which freeze over and normally go through two stratification and two mixing cycles within a year.

DIRECT CURRENT (D.C.) DIRECT CURRENT (D.C.)

Electrical current flowing in one direction only and essentially free from pulsation.

DIRECT FILTRATION DIRECT FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted. Also see CONVENTIONAL FILTRATION and IN-LINE FILTRATION.

DIRECT RUNOFF DIRECT RUNOFF

Water that flows over the ground surface or through the ground directly into streams, rivers, or lakes.

DISCHARGE HEAD DISCHARGE HEAD

The pressure (in pounds per square inch or psi) measured at the centerline of a pump discharge and very close to the discharge flange, converted into feet.

Discharge Head, ft = (Discharge Pressure, psi)(2.31 ft/psi)

DISINFECTION (dis-in-FECK-shun) DISINFECTION

The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

DISTILLATE (DIS-tuh-late) DISTILLATE

In the distillation of a sample, a portion is evaporated; the part that is condensed afterwards is the distillate.

DIVALENT (die-VAY-lent) DIVALENT

Having a valence of two, such as the ferrous ion, Fe^{2+}.

DIVERSION DIVERSION

Use of part of a stream flow as a water supply.

DPD (pronounce as separate letters) DPD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N,N-diethyl-p-phenylene-diamine.

DRAFT DRAFT

(1) The act of drawing or removing water from a tank or reservoir.
(2) The water which is drawn or removed from a tank or reservoir.

DRAWDOWN DRAWDOWN

(1) The drop in the water table or level of water in the ground when water is being pumped from a well.
(2) The amount of water used from a tank or reservoir.
(3) The drop in the water level of a tank or reservoir.

DYNAMIC PRESSURE DYNAMIC PRESSURE

When a pump is operating, the vertical distance (in feet) from a reference point (such as a pump centerline) to the hydraulic grade line is the dynamic head.

Dynamic Pressure, psi = (Dynamic Head, ft) (0.433 psi/ft)

EDUCTOR (e-DUCK-ter) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump. As an injector, it is used to produce vacuum for chlorinators.

EFFECTIVE RANGE EFFECTIVE RANGE

That portion of the design range (usually upper 90 percent) in which an instrument has acceptable accuracy. Also see RANGE and SPAN.

EFFECTIVE SIZE (E.S.) EFFECTIVE SIZE (E.S.)

The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

EFFLUENT (EF-loo-ent) EFFLUENT

Water or other liquid — raw, partially or completely treated — flowing *FROM* a reservoir, basin, treatment process or treatment plant.

EJECTOR EJECTOR

A device used to disperse a chemical solution into water being treated.

ELECTROCHEMICAL REACTION ELECTROCHEMICAL REACTION

Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action). In corrosion, a chemical reaction is accompanied by the flow of electrons through a metallic path. The electron flow may come from an external force and cause the reaction, such as electrolysis caused by a D.C. (direct current) electric railway or the electron flow may be caused by a chemical reaction as in the galvanic action of a flashlight dry cell.

ELECTROCHEMICAL SERIES ELECTROCHEMICAL SERIES

A list of metals with the standard electrode potentials given in volts. The size and sign of the electrode potential indicates how easily these elements will take on or give up electrons, or corrode. Hydrogen is conventionally assigned a value of zero.

ELECTROLYSIS (ee-leck-TRAWL-uh-sis) ELECTROLYSIS

The decomposition of material by an outside electrical current.

ELECTROLYTE (ee-LECK-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

ELECTROLYTIC CELL (ee-LECK-tro-LIT-ick) ELECTROLYTIC CELL

A device in which the chemical decomposition of material causes an electric current to flow. Also, a device in which a chemical reaction occurs as a result of the flow of electric current. Chlorine and caustic (NaOH) are made from salt (NaCl) in eletrolytic cells.

ELECTROMOTIVE FORCE (E.M.F.) ELECTROMOTIVE FORCE (E.M.F.)

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See VOLTAGE.

ELECTROMOTIVE SERIES ELECTROMOTIVE SERIES

A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the Galvanic Series. This is a practical application of the theoretical ELECTROCHEMICAL SERIES.

ELECTRON ELECTRON

An extremely small, negatively charged particle; the part of an atom that determines its chemical properties.

ELEMENT ELEMENT

A substance which cannot be separated into its constituent parts and still retain its chemical identity. For example, sodium (Na) is an element.

END BELLS END BELLS

Devices used to hold the rotor and stator of a motor in position.

END POINT END POINT

Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs. This is called the END POINT of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

ENDEMIC (en-DEM-ick) ENDEMIC

Something peculiar to a particular people or locality, such as a disease which is always present in the population.

ENDRIN (EN-drin) ENDRIN

A pesticide toxic to freshwater and marine aquatic life that produces adverse health effects in domestic water supplies.

ENERGY GRADE LINE (EGL) ENERGY GRADE LINE (EGL)

A line that represents the elevation of energy head of water flowing in a pipe, conduit or channel. The line is drawn above the hydraulic grade line (gradient) a distance equal to the velocity head ($V^2/2g$) of the water flowing at each section or point along the pipe or channel. Also see HYDRAULIC GRADE LINE.

[SEE DRAWING ON PAGE 488]

ENTERIC ENTERIC

Of intestinal origin, especially applied to wastes or bacteria.

ENTRAIN ENTRAIN

To trap bubbles in water either mechanically through turbulence or chemically through a reaction.

ENZYMES (EN-zimes) ENZYMES

Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.

E.P.A. E.P.A.

U.S. **E**nvironmental **P**rotection **A**gency.

EPIDEMIC (EP-uh-DEM-ick) EPIDEMIC

A disease that occurs in a large number of people in a locality at the same time and spreads from person to person.

EPIDEMIOLOGY (EP-uh-DE-me-ALL-o-gee) EPIDEMIOLOGY

A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.

EPILIMNION (EP-uh-LIM-knee-on) EPILIMNION

The upper layer of water in a thermally stratified lake or reservoir. This layer consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.

ESTER ESTER

A compound formed by the reaction between an acid and an alcohol with the elimination of a molecule of water.

EUTROPHIC (you-TRO-fick) EUTROPHIC

Reservoirs and lakes which are rich in nutrients and very productive in terms of aquatic animal and plant life.

EUTROPHICATION (you-TRO-fi-KAY-shun) EUTROPHICATION

The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.

EVAPORATION EVAPORATION

The process by which water or other liquid becomes a gas (water vapor or ammonia vapor).

EVAPOTRANSPIRATION (ee-VAP-o-TRANS-purr-A-shun) EVAPOTRANSPIRATION

The process by which water vapor passes into the atmosphere from living plants. Also called TRANSPIRATION.

FACULTATIVE (FACK-ul-TAY-tive) FACULTATIVE

Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food material such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

FEEDBACK FEEDBACK

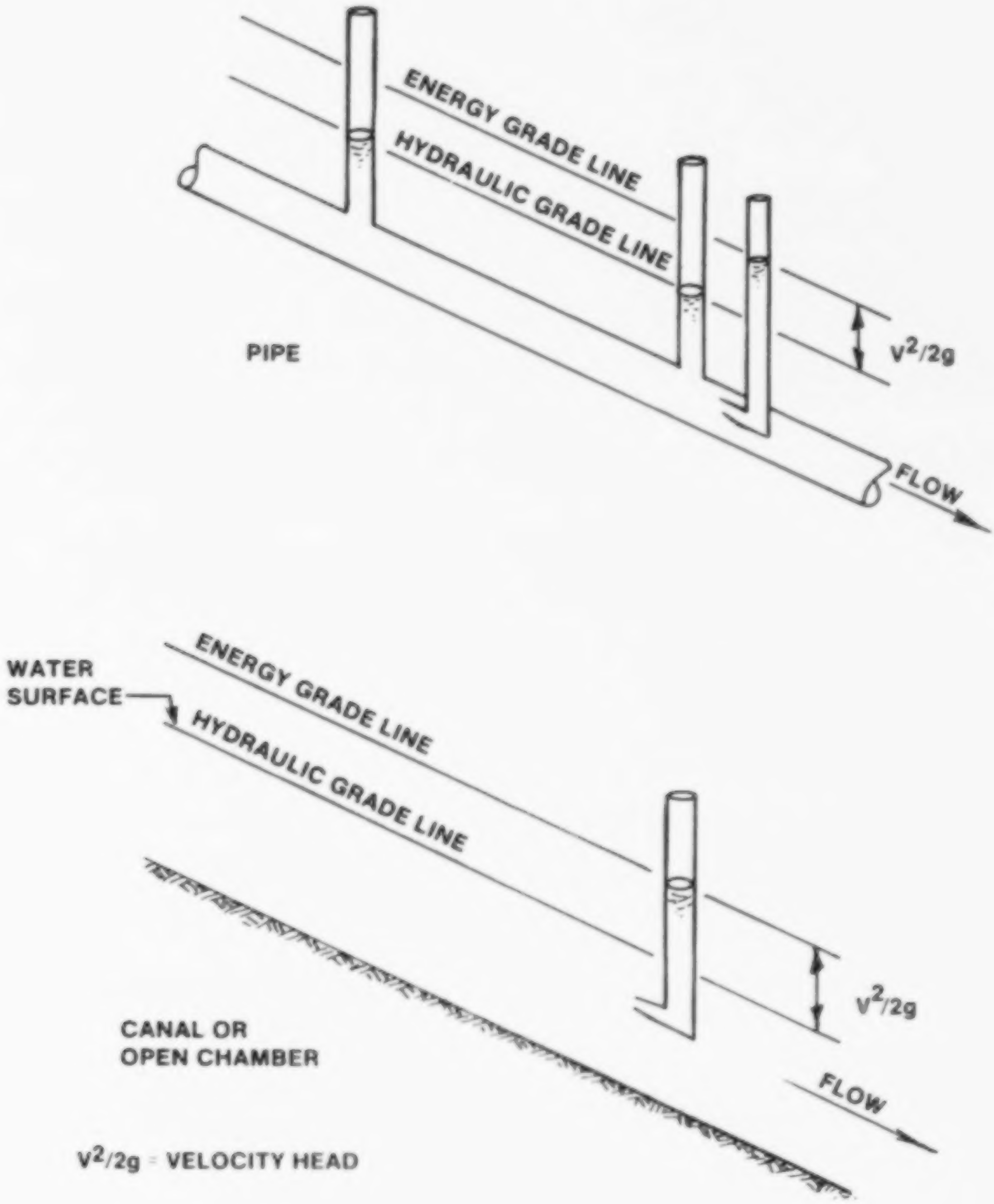
The circulating action between a sensor measuring a process variable and the controller which controls or adjusts the process variable.

FINISHED WATER FINISHED WATER

Water that has passed through a water treatment plant; all the treatment processes are completed or "finished." This water is ready to be delivered to consumers. Also called PRODUCT WATER.

FIX, SAMPLE FIX, SAMPLE

A sample is "fixed" in the field by adding chemicals that prevent the water quality indicators of interest in the sample from changing before final measurements are performed later in the lab.


ENERGY GRADE LINE
HYDRAULIC GRADE LINE
PIPE
$V^2/2g$
FLOW
WATER SURFACE
ENERGY GRADE LINE
HYDRAULIC GRADE LINE
CANAL OR OPEN CHAMBER
$V^2/2g$
FLOW
$V^2/2g$ = VELOCITY HEAD

ENERGY GRADE LINE and HYDRAULIC GRADE LINE

FLAGELLATES (FLAJ-el-LATES) FLAGELLATES

Microorganisms that move by the action of tail-like projections.

FLAME POLISHED FLAME POLISHED

Melted by a flame to smooth out irregularities. Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.

FLOAT ON SYSTEM FLOAT ON SYSTEM

A method of operating a water storage facility. Daily flow into the facility is approximately equal to the average daily demand for water. When consumer demands for water are low, the storage facility will be filling. During periods of high demands, the facility will be emptying.

FLOC FLOC

Clumps of bacteria and particulate impurities that have come together and formed a cluster. Found in flocculation tanks and settling or sedimentation basins.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles after coagulation to form larger particles by a process of gentle mixing.

FLUIDIZED (FLEW-id-I-zd) FLUIDIZED

A mass of solid particles that is made to flow like a liquid by injection of water or gas is said to have been fluidized. In water treatment, a bed of filter media is fluidized by backwashing water through the filter.

FLUORIDATION (FLOOR-uh-DAY-shun) FLUORIDATION

The addition of a chemical to increase the concentration of fluoride ions in drinking water to a predetermined optimum limit to reduce the incidence (number) of dental caries (tooth decay) in children. Defluoridation is the removal of excess fluoride in drinking water to prevent the mottling (brown stains) of teeth.

FLUSHING FLUSHING

A method used to clean water distribution lines. Hydrants are opened and water with a high velocity flows through the pipes, removes deposits from the pipes, and flows out the hydrants.

FLUX FLUX

A flowing or flow.

FOOT VALVE FOOT VALVE

A special type of check valve located at the bottom end of the suction pipe on a pump. This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe.

FREE AVAILABLE RESIDUAL CHLORINE FREE AVAILABLE RESIDUAL CHLORINE

That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

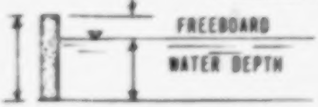
FREE RESIDUAL CHLORINATION FREE RESIDUAL CHLORINATION

The application of chlorine to water to produce a free available chlorine residual equal to at least 80 percent of the total residual chlorine (sum of free and combined available chlorine residual).

FREEBOARD FREEBOARD

(1) The vertical distance from the normal water surface to the top of the confining wall.

(2) The vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called AVAILABLE EXPANSION.



FRICTION LOSSES FRICTION LOSSES

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, and restrictions caused by fittings. Water flowing in a pipe loses pressure or energy as a result of friction losses. Also see HEAD LOSS.

FUNGI (FUN-ji) FUNGI

Mushrooms, molds, mildews, rusts, and smuts that are small non-chlorophyll-bearing plants lacking roots, stems and leaves. They occur in natural waters and grow best in the absence of light. Their decomposition may cause objectionable tastes and odors in water.

GAGE PRESSURE GAGE PRESSURE

The pressure within a closed container or pipe as measured with a gage. In contrast, absolute pressure is the sum of atmospheric pressure (14.7 lbs/sq in) *PLUS* pressure within a vessel (as measured by a gage). Most pressure gages read in "gage pressure" or psig (pounds per square inch gage pressure).

GALVANIC CELL GALVANIC CELL

An eletrolytic cell capable of producing electrical energy by electrochemical action. The decomposition of materials in the cell causes an electric (electron) current to flow from cathode to anode.

GALVANIC SERIES GALVANIC SERIES

A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the ELECTROMOTIVE SERIES. This is a practical application of the theoretical ELECTROCHEMICAL SERIES.

GALVANIZE GALVANIZE

To coat a metal (especially iron or steel) with zinc. Galvanization is the process of coating a metal with zinc.

GARNET (GAR-nit) GARNET

A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

GAUGE, PIPE GAUGE, PIPE

A number that defines the thickness of the sheet used to make steel pipe. The larger the number, the thinner the pipe wall.

GEOLOGICAL LOG GEOLOGICAL LOG

A detailed description of all underground features discovered during the drilling of a well (depth, thickness and type of formations).

GEOPHYSICAL LOG GEOPHYSICAL LOG

A record of the structure and composition of the earth encountered when drilling a well or similar type of test hole or boring.

GERMICIDE (GERM-uh-SIDE) GERMICIDE

A substance formulated to kill germs or microorganisms. The germicidal properties of chlorine make it an effective disinfectant.

GIARDIASIS (gee-are-DYE-uh-sis) GIARDIASIS

Intestinal disease caused by an infestation of Giardia flagellates.

GRAB SAMPLE GRAB SAMPLE

A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

GRADE GRADE

(1) The elevation of the invert (lowest point) of the bottom of a pipeline, canal, culvert or similar conduit.

(2) The inclination or slope of a pipeline, conduit, stream channel, or natural ground surface; usually expressed in terms of the ratio or percentage of number of units of vertical rise or fall per unit of horizontal distance. A 0.5 percent grade would be a drop of one-half foot per hundred feet of pipe.

GRAVIMETRIC GRAVIMETRIC

A means of measuring unknown concentrations of water quality indicators in a sample by WEIGHING a precipitate or residue of the sample.

GREENSAND GREENSAND

A sand which looks like ordinary filter sand except that it is green in color. This sand is a natural ion exchange mineral which is capable of softening water.

HARD WATER HARD WATER

Water having a high concentration of calcium and magnesium ions. A water may be considered hard if it has a hardness greater than the typical hardness of water from the region. Some textbooks define hard water as water with a hardness of more than 100 mg/*L* as calcium carbonate.

HARDNESS, WATER HARDNESS, WATER

A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water.

HEAD HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

HEAD LOSS HEAD LOSS

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as a result of friction losses. Also see FRICTION LOSSES.

HEADER HEADER

A large pipe to which a series of smaller pipes are connected. Also called a MANIFOLD.

HEAT SENSOR HEAT SENSOR

A device that opens and closes a switch in response to changes in the temperature. This device might be a metal contact, or a thermocouple which generates a minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a TEMPERATURE SENSOR.

HECTARE (HECK-tar) HECTARE

A measure of area in the metric system similar to an acre. One hectare is equal to 10,000 square meters and 2.4711 acres.

HEPATITIS (HEP-up-TIE-tis) HEPATITIS

Hepatitis is an inflammation of the liver usually caused by an acute viral infection. Yellow jaundice is one symptom of hepatitis.

HERBICIDE (HERB-uh-SIDE) HERBICIDE

A compound, usually a man-made organic chemical, used to kill or control plant growth.

HERTZ HERTZ

The number of complete electromagnetic cycles or waves in one second of an electrical or electronic circuit. Also called the frequency of the current. Abbreviated Hz.

HIGH-LINE JUMPERS HIGH-LINE JUMPERS

Pipes or hoses connected to fire hydrants and laid on top of the ground to provide emergency water service for an isolated portion of a distribution system.

HOSE BIB HOSE BIB

Faucet. A location in a water line where a hose is connected.

HTH (pronounce as separate letters) HTH

High **T**est **H**ypochlorite. Calcium hypochlorite or $Ca(OCl)_2$

HYDRATED LIME HYDRATED LIME

Limestone that has been "burned" and treated with water under controlled conditions until the calcium oxide portion has been converted to calcium hydroxide ($Ca(OH)_2$). Hydrated lime is quicklime combined with water. $CaO + H_2O \rightarrow Ca(OH)_2$. Also see QUICKLIME.

HYDRAULIC GRADE LINE (HGL) HYDRAULIC GRADE LINE (HGL)

The surface or profile or water flowing in an open channel or a pipe flowing partially full. If a pipe is under pressure, the hydraulic grade line is at the level water would rise to in a small vertical tube connected to the pipe. Also see ENERGY GRADE LINE.

[SEE DRAWING ON PAGE 488]

HYDRAULIC GRADIENT HYDRAULIC GRADIENT

The slope of the hydraulic grade line. This is the slope of the water surface in an open channel, the slope of the water surface of the groundwater table, or the slope of the water pressure for pipes under pressure.

HYDROGEOLOGIST (HI-dro-gee-ALL-uh-gist) HYDROGEOLOGIST

A person who studies and works with groundwater.

HYDROLOGIC CYCLE (HI-dro-LOJ-ick) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean. Also called the WATER CYCLE.

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

A chemical reaction in which a compound is converted into another compound by taking up water.

HYDROPHILIC (HI-dro-FILL-ick) HYDROPHILIC

Having a strong affinity (liking) for water. The opposite of HYDROPHOBIC.

HYDROPHOBIC (HI-dro-FOE-bick) HYDROPHOBIC

Having a strong aversion (dislike) for water. The opposite of HYDROPHILIC.

HYDROPNEUMATIC (HI-dro-new-MAT-ick) HYDROPNEUMATIC

A water system, usually small, in which a water pump is automatically controlled (started and stopped) by the air pressure in a compressed-air tank.

HYDROSTATIC PRESSURE (HI-dro-STAT-ick) HYDROSTATIC PRESSURE

(1) The pressure at a specific elevation exerted by a body of water at rest, or

(2) In the case of groundwater, the pressure at a specific elevation due to the weight of water at higher levels in the same zone of saturation.

HYPOCHLORINATION (HI-poe-KLOR-uh-NAY-shun) HYPOCHLORINATION

The application of hypochlorite compounds to water for the purpose of disinfection.

HYPOCHLORINATORS (HI-poe-KLOR-uh-NAY-tors) HYPOCHLORINATORS

Chlorine pumps, chemical feed pumps or devices used to dispense chlorine solutions made from hypochlorites such as bleach (sodium hypochlorite) or calcium hypochlorite into the water being treated.

HYPOCHLORITE (HI-poe-KLOR-ite) HYPOCHLORITE

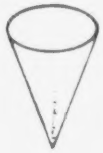
Chemical compounds containing available chlorine; used for disinfection. They are available as liquids (bleach) or solids (powder, granules and pellets). Salts of hypochlorous acid.

HYPOLIMNION (HI-poe-LIM-knee-on) HYPOLIMNION

The lowest layer in a thermally stratified lake or reservoir. This layer consists of colder, more dense water, has a constant temperature and no mixing occurs.

IMHOFF CONE IMHOFF CONE

A clear, cone-shaped container marked with graduations. The cone is used to measure the volume of settleable solids in a specific volume (usually one liter) of water.



IMPELLER IMPELLER

A rotating set of vanes in a pump designed to pump or lift water.

IMPERMEABLE (im-PURR-me-uh-BULL) IMPERMEABLE

Not easily penetrated. The property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water.

INDICATOR (CHEMICAL) INDICATOR (CHEMICAL)

A substance that gives a visible change, usually of color, at a desired point in a chemical reaction, generally at a specified end point.

INDICATOR (INSTRUMENT) INDICATOR (INSTRUMENT)

A device which indicates the result of a measurement. Most indicators in the water utility field use either a fixed scale and movable indicator (pointer) such as a pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called a RECEIVER.

INFILTRATION (IN-fill-TRAY-shun) INFILTRATION

The gradual flow or movement of water into and through (to percolate or pass through) the pores of the soil. Also called PERCOLATION.

INFLUENT (IN-flu-ent) INFLUENT

Water or other liquid — raw or partially treated — flowing *INTO* a reservoir, basin, treatment process or treatment plant.

IN-LINE FILTRATION IN-LINE FILTRATION

The addition of chemical coagulants directly to the filter inlet pipe. The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated. This pretreatment method is commonly used in pressure filter installation. Also see CONVENTIONAL FILTRATION and DIRECT FILTRATION.

INORGANIC INORGANIC

Material such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

INPUT HORSEPOWER INPUT HORSEPOWER

The total power used in operating a pump and motor.

$$\text{Input Horsepower, HP} = \frac{(\text{Brake Horsepower,HP})(100\%)}{\text{Motor Efficiency, }\%}$$

INSECTICIDE INSECTICIDE

Any substance or chemical formulated to kill or control insects.

INTEGRATOR INTEGRATOR

A device or meter that continuously measures and calculates (adds) total flows in gallons, or million cubic feet, or some other unit of volume measurement. Also called a TOTALIZER.

INTERFACE INTERFACE

The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).

INTERLOCK INTERLOCK

An electrical switch, usually magnetically operated. Used to interrupt all (local) power to a panel or device when the door is opened or the circuit exposed to service.

INTERNAL FRICTION INTERNAL FRICTION

Friction within a fluid (water) due to cohesive forces.

INTERSTICE (in-TUR-stuhz) INTERSTICE

A very small open space in a rock or granular material. Also called a void or void space. Also see PORE.

INVERT (IN-vert) INVERT

The lowest point of the channel inside a pipe, conduit, or canal.

ION ION

An electrically charged atom, radical (such as SO_4^{2-}), or molecule formed by the loss or gain of one or more electrons.

IONIC CONCENTRATION IONIC CONCENTRATION

The concentration of any ion in solution, usually expressed in moles per liter.

IONIZATION (EYE-on-uh-ZAY-shun) IONIZATION

The splitting or dissociation (separation) of molecules into negatively and positively charged ions.

JAR TEST JAR TEST

A laboratory procedure that simulates a water treatment plant's coagulation/flocculation units with differing chemical doses and also energy of rapid mix, energy of slow mix, and settling time. The purpose of this procedure is to *ESTIMATE* the minimum or ideal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of chemicals are added to each jar, stirred and the settling of solids is observed. The dose of chemicals that provides satisfactory settling removal of turbidity and/or color is the dose used to treat the water being taken into the plant at that time. When evaluating the results of a jar test, the operator should also consider the floc quality in the flocculation area and the floc loading on the filter.

JOGGING JOGGING

The frequent starting and stopping of an electric motor.

JOULE (jewel) JOULE

A measure of energy, work or quantity of heat. One joule is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of force.

KELLY KELLY

The square section of a rod which causes the rotation of the drill bit. Torque from a drive table is applied to the square rod to cause the rotary motion. The drive table is chain or gear driven by an engine.

KILO KILO

(1) Kilogram.
(2) Kilometer.
(3) A prefix meaning "thousand" used in the metric system and other scientific systems of measurement.

KINETIC ENERGY KINETIC ENERGY

Energy possessed by a moving body of matter, such as water, as a result of its motion.

KJELDAHL NITROGEN (KELL-doll) KJELDAHL NITROGEN

Nitrogen in the form of organic proteins or their decomposition product ammonia, as measured by the Kjeldahl Method.

LANGELIER INDEX (L.I.) LANGELIER INDEX (L.I.)

An index reflecting the equilibrium pH of a water with respect to calcium and alkalinity. This index is used in stabilizing water to control both corrosion and the deposition of scale.

Langelier Index = $pH - pH_s$
where pH = actual pH of the water, and
pH_s = pH at which the water, having the same alkalinity and calcium content, is just saturated with calcium carbonate.

LAUNDERING WEIR (LAWN-der-ing weer) LAUNDERING WEIR

Sedimentation basin overflow weir. A plate with V-notches along the top to assure a uniform flow rate and avoid short-circuiting.

LAUNDERS (LAWN-ders) LAUNDERS

Sedimentation basin and filter discharge channels, consisting of overflow weir plates (in sedimentation basins) and conveying troughs.

LEATHERS LEATHERS

O rings or gaskets used with piston pumps to provide a seal between the piston and the side wall.

LEVEL CONTROLS LEVEL CONTROLS

A float device (or pressure switch) which senses changes in a measured variable and opens or closes a switch in response to that change. In its simplest form, this control might be a floating ball connected mechanically to a switch or valve such as is used to stop water flow into a toilet when the tank is full.

LINDANE (LYNN-dane) LINDANE

A pesticide that causes adverse health effects in domestic water supplies and also is toxic to freshwater and marine aquatic life.

LINEARITY (LYNN-ee-AIR-it-ee) LINEARITY

How closely an instrument measures actual values of a variable through its effective range; a measure used to determine the accuracy of an instrument.

LITTORAL ZONE (LIT-or-al) LITTORAL ZONE

(1) That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants.
(2) The strip of land along the shoreline between the high and low water levels.

LOGARITHM (LOG-a-rith-m) LOGARITHM

The exponent that indicates the power to which a number must be raised to produce a given number. For example: if $B^2 = N$, the 2 is the logarithm of N (to the base B), or $10^2 = 100$ and $\log_{10} 100 = 2$. Also abbreviated to "log."

LOGGING, ELECTRICAL LOGGING, ELECTRICAL

A procedure used to determine the porosity (spaces or voids) of formations in search of water-bearing formations (aquifers). Electrical probes are lowered into wells, an electrical current is induced at various depths, and the resistance measured of various formations indicates the porosity of the material.

M or MOLAR **M** or MOLAR

A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A one *M* solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

MACROSCOPIC (MACK-row-SKAWP-ick) ORGANISMS MACROSCOPIC ORGANISMS

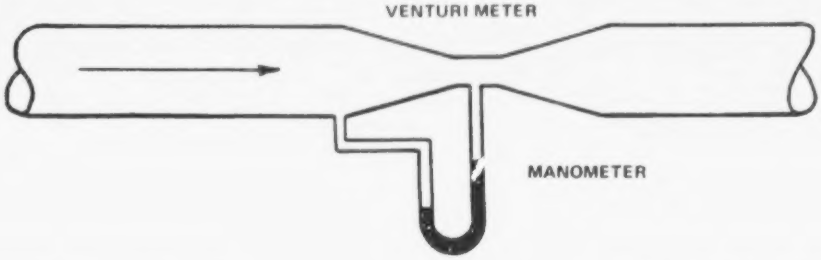
Organisms big enough to be seen by the eye without the aid of a microscope.

MANIFOLD MANIFOLD

A large pipe to which a series of smaller pipes are connected. Also called a HEADER.

MANOMETER (man-NAH-mut-ter) MANOMETER

An instrument for measuring pressure. Usually, a manometer is a glass tube filled with a liquid that is used to measure the difference in pressure across a flow-measuring device such as an orifice or Venturi meter. The instrument used to measure blood pressure is a type of manometer.



MATERIAL SAFETY DATA SHEET (MSDS) MATERIAL SAFETY DATA SHEET (MSDS)

A document which provides pertinent information and a profile of a particular hazardous substance or mixture. An MSDS is normally developed by the manufacturer or formulator of the hazardous substance or mixture. The MSDS is required to be made available to employers and operators whenever there is the likelihood of the hazardous substance or mixture being introduced into a workplace.

MAXIMUM CONTAMINANT LEVEL (MCL) MAXIMUM CONTAMINANT LEVEL (MCL)

See MCL.

MBAS MBAS

Methylene - **B**lue - **A**ctive **S**ubstances. These substances are used in surfactants or detergents.

MCL MCL

Maximum **C**ontaminant **L**evel. The largest allowable amount. MCLs for various water quality indicators are specified in the National Interim Primary Drinking Water Regulations (NIPDWR).

MEASURED VARIABLE MEASURED VARIABLE

A characteristic or component part that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

MECHANICAL JOINT MECHANICAL JOINT

A flexible device that joins pipes or fittings together by the use of lugs and bolts.

MEG MEG

A procedure used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEGGER.

MEGGER (from megohm) MEGGER

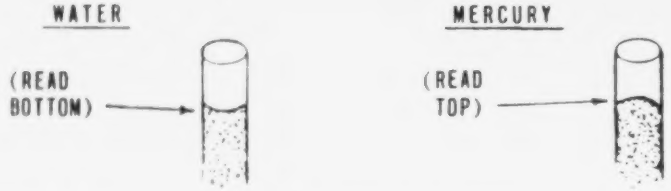
An instrument used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEG.

MEGOHM MEGOHM

Meg means one million, so 5 megohms means 5 million ohms. A megger reads in millions of ohms.

MENISCUS (meh-NIS-cuss) MENISCUS

The curved top of a column of liquid (water, oil, mercury) in a small tube. When the liquid wets the sides of the container (as with water), the curve forms a valley. When the confining sides are not wetted (as with mercury), the curve forms a hill or upward bulge.



MESH MESH

One of the openings or spaces in a screen or woven fabric. The value of the mesh is usually given as the number of openings per inch. This value does not consider the diameter of the wire or fabric; therefore, the mesh number does not always have a definite relationship to the size of the hole.

MESOTROPHIC (MESS-o-TRO-fick) MESOTROPHIC

Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

METABOLISM (meh-TAB-uh-LIZ-um) METABOLISM

(1) The biochemical processes in which food is used and wastes are formed by living organisms.

(2) All biochemical reactions involved in cell formation and growth.

METALIMNION (MET-uh-LIM-knee-on) METALIMNION

The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the THERMOCLINE.

METHOXYCHLOR (meth-OXY-klor) METHOXYCHLOR

A pesticide which causes adverse health effects in domestic water supplies and is also toxic to freshwater and marine aquatic life. The chemical name for methoxychlor is 2,2-bis (p-methoxyphenol)-1,1,1-trichloroethane.

METHYL ORANGE ALKALINITY METHYL ORANGE ALKALINITY

A measure of the total alkalinity in a water sample. The alkalinity is measured by the amount of standard sulfuric acid required to lower the pH of the water to a pH level of 4.5, as indicated by the change in color of methyl orange from orange to pink. Methyl orange alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

mg/*L* mg/*L*

See MILLIGRAMS PER LITER.

MICROBIAL GROWTH (my-KROW-bee-ul) MICROBIAL GROWTH

The activity and growth of microorganisms such as bacteria, algae, diatoms, plankton and fungi.

MICRON (MY-kron) MICRON

A unit of length. One millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

MICROORGANISMS (MY-crow-OR-gan-IS-zums) MICROORGANISMS

Living organisms that can be seen individually only with the aid of a microscope.

MIL MIL

A unit of length equal to 0.001 of an inch. The diameter of wires and tubing is measured in mils, as is the thickness of plastic sheeting.

MILLIGRAMS PER LITER, mg/*L* MILLIGRAMS PER LITER, mg/*L*

A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/*L* of a substance in fresh water is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams. If it contains 10 milligrams of calcium, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/*L*), or 10 parts of calcium per million parts of water, or 10 parts per million (10 ppm).

MILLIMICRON (MILL-uh-MY-kron) MILLIMICRON

A unit of length equal to $10^{-3}\mu$ (one thousandth of a micron), 10^{-6} millimeters, or 10^{-9} meters; correctly called a nanometer, nm.

MOLAR MOLAR

See **M** for MOLAR.

MOLE MOLE

The molecular weight of a substance, usually expressed in grams.

MOLECULAR WEIGHT MOLECULAR WEIGHT

The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
O	16	4	64
			98

MOLECULE (MOLL-uh-KULE) MOLECULE

The smallest division of a compound that still retains or exhibits all the properties of the substance.

MONOMER (MON-o-MER) MONOMER

A molecule of low molecular weight capable of reacting with identical or different monomers to form polymers.

MONOMICTIC (mo-no-MICK-tick) MONOMICTIC

Lakes and reservoirs which are relatively deep, do not freeze over during the winter months, and undergo a single stratification and mixing cycle during the year. These lakes and reservoirs usually become destratified during the mixing cycle, usually in the fall of the year.

MONOVALENT MONOVALENT

Having a valence of one, such as the cuprous (copper) ion, Cu^+.

MOST PROBABLE NUMBER (MPN) MOST PROBABLE NUMBER (MPN)

See MPN.

MOTILE (MO-till) MOTILE

Capable of self-propelled movement. A term that is sometimes used to distinguish between certain types of organisms found in water.

MOTOR EFFICIENCY MOTOR EFFICIENCY

The ratio of energy delivered by a motor to the energy supplied to it during a fixed period or cycle. Motor efficiency ratings will vary depending upon motor manufacturer and usually will range from 88.9 to 90.0 percent.

MPN (pronounce as separate letters) MPN

MPN is the Most Probable Number of coliform-group organisms per unit volume of sample water. Expressed as the number of organisms per 100 m*L* of sample water.

MUDBALLS MUDBALLS

Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. This material forms in filters and gradually increases in size when not removed by the backwashing process.

MULTI-STAGE PUMP MULTI-STAGE PUMP

A pump that has more than one impeller. A single-stage pump has one impeller.

N or NORMAL N or NORMAL

A normal solution contains one gram equivalent weight of reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A one *N* solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.

NATIONAL ENVIRONMENTAL TRAINING ASSOCIATION NATIONAL ENVIRONMENTAL TRAINING ASSOCIATION

A professional organization devoted to serving the environment trainer and promoting better operation of waterworks and pollution control facilities. For information on NETA membership and publications, contact NETA, 8687 Via de Ventura, Suite 214, Scottsdale, Arizona 85258.

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH

See NIOSH.

NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

Commonly referred to as NIPDWR.

NATIONAL SAFE DRINKING WATER REGULATIONS

NATIONAL SAFE DRINKING WATER REGULATIONS

Commonly referred to as NSDWR.

NEPHELOMETRIC (NEFF-el-o-MET-rick)

NEPHELOMETRIC

A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

NETA

NETA

See **N**ational **E**nvironmental **T**raining **A**ssociation.

NEWTON

NEWTON

A force which, when applied to a body having a mass of one kilogram, gives it an acceleration of one meter per second per second.

NIOSH

NIOSH

The **N**ational **I**nstitute of **O**ccupational **S**afety and **H**ealth is an organization that tests and approves safety equipment for particular applications. NIOSH is the primary Federal agency engaged in research in the national effort to eliminate on-the-job hazards to the health and safety of working people. The NIOSH Publications Catalog contains a listing of NIOSH publications mainly on industrial hygiene and occupational health. To obtain a copy of the catalog, write to NIOSH Publications, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

NIPDWR

NIPDWR

National **I**nterim **P**rimary **D**rinking **W**ater **R**egulations.

NITROGENOUS (nye-TRAH-jen-us)

NITROGENOUS

A term used to describe chemical compounds (usually organic) containing nitrogen in combined forms. Proteins and nitrates are nitrogenous compounds.

NOBLE METAL

NOBLE METAL

A chemically inactive metal (such as gold). A metal that does not corrode easily and is much scarcer (and more valuable) than the so-called useful or base metals. Also see BASE METAL.

NOMINAL DIAMETER

NOMINAL DIAMETER

An approximate measurement of the diameter of a pipe. Although the nominal diameter is used to describe the size or diameter of a pipe, it is usually not the exact inside diameter of the pipe.

NONIONIC POLYMER (NON-eye-ON-ick)

NONIONIC POLYMER

A polymer that has no net eletrical charge.

NONPOINT SOURCE

NONPOINT SOURCE

A runoff or discharge from a field or similar source. A point source refers to a discharge that comes out the end of a pipe.

NONPOTABLE (non-POE-tuh-bull)

NONPOTABLE

Water that may contain objectionable pollution, contamination, minerals, or infective agents and is considered unsafe and/or unpalatable for drinking.

NORMAL

NORMAL

See **N** for NORMAL.

NPDES PERMIT

NPDES PERMIT

National **P**ollutant **D**ischarge **E**limination **S**ystem permit is the regulatory agency document designed to control all discharges of pollutants from point sources in U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

NSDWR NSDWR

National **S**afe **D**rinking **W**ater **R**egulations.

NUTRIENT NUTRIENT

Any substance that is assimilated (taken in) by organisms and promotes growth. Nitrogen and phosphorous are nutrients which promote the growth of algae. There are other essential and trace elements which are also considered nutrients.

OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970 OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970

See OSHA.

ODOR THRESHOLD ODOR THRESHOLD

The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called THRESHOLD ODOR.

OFFSET (or DROOP) OFFSET

The difference between the actual value and the desired value (or set point); characteristic of proportional controllers that do not incorporate reset action.

OHM OHM

The unit of electrical resistance. The resistance of a conductor in which one volt produces a current of one ampere.

OLFACTORY FATIGUE (oh-FAK-tore-ee) OLFACTORY FATIGUE

A condition in which a person's nose, after exposure to certain odors, is no longer able to detect the odor.

OLIGOTROPHIC (AH-lig-o-TRO-fick) OLIGOTROPHIC

Reservoirs and lakes which are nutrient poor and contain little aquatic plant or animal life.

ORGANIC ORGANIC

Substances that come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical substances of mineral origin.) Also see INORGANIC.

ORGANICS ORGANICS

(1) A term used to refer to chemical compounds made from carbon molecules. These compounds may be natural materials (such as animal or plant sources) or man-made materials (such as synthetic organics). Also see ORGANIC.

(2) Any form of animal of plant life. Also see BACTERIA.

ORGANISM ORGANISM

Any form of animal or plant life. Also see BACTERIA.

ORIFICE (OR-uh-fiss) ORIFICE

An opening (hole) in a plate, wall or partition. An orifice flange or plate placed in a pipe consists of a slot or a calibrated circular hole smaller than the pipe diameter. The difference in pressure in the pipe above and at the orifice may be used to determine the flow in the pipe.

ORP ORP

Oxidation-**R**eduction **P**otential. The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

ORTHOTOLIDINE (or-tho-TOL-uh-dine) ORTHOTOLIDINE

Orthotolidine is a colorimetric indicator of chlorine residual. If chlorine is present, a yellow-colored compound is produced. This reagent is no longer approved for chemical analysis.

OSHA (O-shuh) OSHA

The Williams-Steiger **O**ccupational **S**afety and **H**ealth **A**ct of 1970 (OSHA) is a law designed to protect the health and safety of industrial workers and also the operators of water supply systems and treatment plants.

OSMOSIS (oz-MOE-sis) OSMOSIS

The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). This process tends to equalize the conditions on either side of the membrane.

OVERALL EFFICIENCY, PUMP OVERALL EFFICIENCY, PUMP

The combined efficiency of a pump and motor together. Also called the WIRE-TO-WATER EFFICIENCY.

OVERDRAFT OVERDRAFT

The pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin. This pumping results in a depletion or "mining" of the groundwater in the basin.

OVERFLOW RATE OVERFLOW RATE

One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called SURFACE LOADING.

$$\text{Overflow Rate, GDP/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

OVERTURN OVERTURN

The almost spontaneous mixing of all layers of water in a reservoir or lake when the water temperature becomes similar from top to bottom. This may occur in the fall/winter when the surface waters cool to the same temperature as the bottom waters and also in the spring when the surface waters warm after the ice melts.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDATION-REDUCTION POTENTIAL OXIDATION-REDUCTION POTENTIAL

The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

OXIDIZING AGENT OXIDIZING AGENT

Any substance, such as oxygen (O_2) or chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a REDUCING AGENT.

OXYGEN DEFICIENCY OXYGEN DEFICIENCY

An atmosphere containing oxygen at a concentration of less than 19.5 percent by volume.

OZONATION (O-zoe-NAY-shun) OZONATION

The application of ozone to water for disinfection or for taste and odor control.

PACKER ASSEMBLY PACKER ASSEMBLY

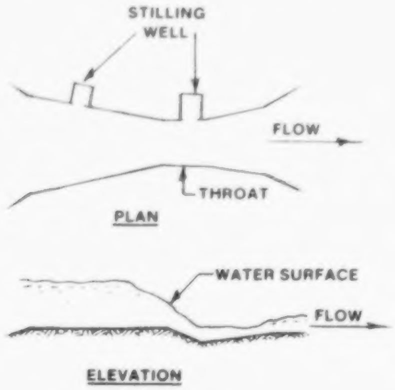
An inflatable device used to seal the tremie pipe inside the well casing to prevent the grout from entering the inside of the conductor casing.

PALATABLE (PAL-a-ta-ble) PALATABLE

Water at a desirable temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

PARSHALL FLUME PARSHALL FLUME

A device used to measure the flow in an open channel. The flume narrows to a throat of fixed dimensions and then expands again. The rate of flow can be calculated by measuring the difference in head (pressure) before and at the throat of the flume.



PARTICLE COUNT PARTICLE COUNT

The results of a microscopic examination of treated water with a special "particle counter" which classifies suspended particles by number and size.

PARTICULATE (par-TICK-you-let) PARTICULATE

A very small solid suspended in water which can vary widely in size, shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.

PARTS PER MILLION (PPM) PARTS PER MILLION (PPM)

Parts per million parts, a measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/*L*) which is the preferred term.

PASCAL PASCAL

The pressure or stress of one newton per square meter. (Abbreviated Pa)

1 psi = 6895 Pa = 6.895 kN/sq m = 0.0703 kg/sq cm

PATHOGENIC ORGANISMS (path-o-JEN-ick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of organisms which do *NOT* cause disease. These organisms are called non-pathogenic.

PATHOGENS (PATH-o-jens) PATHOGENS

Pathogenic or disease-causing organisms.

PCBs PCBs

See POLYCHLORINATED BIPHENYLS.

PEAK DEMAND PEAK DEMAND

The maximum momentary load placed on a water treatment plant, pumping station or distribution system. This demand is usually the maximum average load in one hour or less, but may be specified as the instantaneous or with some other short time period.

PERCENT SATURATION PERCENT SATURATION

The amount of a substance that is dissolved in a solution compared with the amount that could be dissolved in the solution, expressed as a percent.

$$\text{Percent Saturation, \%} = \frac{\text{Amount of Substance That is Dissolved}}{\text{Amount That Could Be Dissolved in Solution}} \times 100\%$$

PERCOLATING WATER (PURR-co-LAY-ting) PERCOLATING WATER

Water that passes through soil or rocks under the force of gravity.

PERCOLATION (PURR-ko-LAY-shun) PERCOLATION

The slow passage of water through a filter medium; or, the gradual penetration of soil and rocks by water.

PERIPHYTON (puh-RIF-uh-tawn) PERIPHYTON

Microscopic plants and animals that are firmly attached to solid surfaces under water such as rocks, logs, pilings and other structures.

PERMEABILITY (PURR-me-uh-BILL-uh-tee) PERMEABILITY

The property of a material or soil that permits considerable movement of water through it when it is saturated.

PERMEATE (PURR-me-ate) PERMEATE

To penetrate and pass through, as water penetrates and passes through soil and other porous materials.

P[illegible]TICIDE PESTICIDE

[illegible] substance or chemical designed or formulated to kill or control weeds or animal pests. Also see ALGICIDE, HERBICIDE, [illegible]CTICIDE,and RODENTICIDE.

PET COCK PET COCK

A small valve or faucet used to drain a cylinder or fitting.

pH (pronounce as separate letters) pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$\text{pH} = \text{Log}\ \frac{1}{(H^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

PHENOLIC COMPOUNDS (FEE-noll-LICK) PHENOLIC COMPOUNDS

Organic compounds that are derivatives of benzene.

PHENOLPHTHALEIN ALKALINITY (FEE-nol-THAY-leen) PHENOLPHTHALEIN ALKALINITY

The alkalinity in a water sample measured by the amount of standard acid required to lower the pH to a level of 8.3, as indicated by the change in color of phenolphthalein from pink to clear. Phenolphthalein alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

PHOTOSYNTHESIS (foe-tow-SIN-thuh-sis) PHOTOSYNTHESIS

A process in which organisms, with the aid of chlorophyll (green plant enzyme), convert carbon dioxide and inorganic substances into oxygen and additional plant material, using sunlight for energy. All green plants grow by this process.

PHYTOPLANKTON (FI-tow-PLANK-ton) PHYTOPLANKTON

Small, usually microscopic plants (such as algae), found in lakes, reservoirs, and other bodies of water.

PICO PICO

A prefix used in the metric system and other scientific systems of measurement which means 10^{-12} or 0.000 000 000 001.

PICOCURIE PICOCURIE

A measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second.

PITLESS ADAPTER PITLESS ADAPTER

A fitting which allows the well casing to be extended above ground while having a discharge connection located below the frost line. Advantages of using a pitless adapter include the elimination of the need for a pit or pump house and it is a water-tight design, which helps maintain a sanitary water supply.

PLAN VIEW PLAN VIEW

A diagram or photo showing a facility as it would appear when looking down on top of it.

PLANKTON PLANKTON

(1) Small, usually microscopic, plants (phytoplankton) and animals (zooplankton) in aquatic systems.

(2) All of the smaller floating, suspended or self-propelled organisms in a body of water.

PLUG FLOW PLUG FLOW

A type of flow that occurs in tanks, basins or reactors when a slug of water moves through a tank without ever dispersing or mixing with the rest of the water flowing through the tank.

PMCLs PMCLs

Primary **M**aximum **C**ontaminant **L**evels. Primary MCLs for various water quality indicators are established to protect public health.

POINT SOURCE POINT SOURCE

A discharge that comes out of the end of a pipe. A nonpoint source refers to runoff or a discharge from a field or similar source.

POLE SHADER POLE SHADER

A copper bar circling the laminated iron core inside the coil of a magnetic starter.

POLLUTION POLLUTION

The impairment (reduction) of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes), to a degree that has an adverse effect on any beneficial use of water.

POLYCHLORINATED BIPHENYLS POLYCHLORINATED BIPHENYLS

A class of organic compounds that cause adverse health effects in domestic water supplies.

POLYELECTROLYTE (POLLY-ee-LECK-tro-lite) POLYELECTROLYTE

A high-molecular-weight (relatively heavy) substance having points of positive or negative electrical charges that is formed by either natural or man-made processes. Natural polyelectrolytes may be of biological origin or derived from starch products and cellulose derivatives. Man-made polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. Often called a POLYMER.

POLYMER POLYMER

A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

PORE PORE

A very small open space in a rock or granular material. Also see INTERSTICE.

POROSITY POROSITY

(1) A measure of the spaces or voids in a material or aquifer.

(2) The ratio of the volume of spaces in a rock or soil to the total volume. This ratio is usually expressed as a percentage.

$$\text{Porosity, \%} = \frac{(\text{Volume of Spaces})(100\%)}{\text{Total Volume}}$$

POSITIVE BACTERIOLOGICAL SAMPLE POSITIVE BACTERIOLOGICAL SAMPLE

A water sample in which gas is produced by coliform organisms during incubation in the multiple tube fermentation test. See Chapter 11, Lab Procedures, "Coliform Test," for details.

POSITIVE DISPLACEMENT PUMP POSITIVE DISPLACEMENT PUMP

A type of piston, diaphragm, gear or screw pump that delivers a constant volume with each stroke. Positive displacement pumps are used as chemical solution feeders.

POSTCHLORINATION POSTCHLORINATION

The addition of chlorine to the plant effluent, *FOLLOWING* plant treatment, for disinfection purposes.

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

POWER FACTOR POWER FACTOR

The ratio of the true power passing through an electric circuit to the product of the voltage and amperage in the circuit. This is a measure of the lag or load of the current with respect to the voltage.

PPM PPM

See PARTS PER MILLION.

PRECHLORINATION PRECHLORINATION

The addition of chlorine at the headworks of the plant *PRIOR TO* other treatment processes mainly for disinfection and control of tastes, odors and aquatic growths. Also applied to aid in coagulation and settling.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

PRECIPITATION (pre-SIP-uh-TAY-shun) PRECIPITATION

(1) The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, or other forms of moisture.

(2) The chemical transformation of a substance in solution into an insoluble form (precipitate).

PRECISION PRECISION

The ability of an instrument to measure a process variable and to repeatedly obtain the same result. The ability of an instrument to reproduce the same results.

PRECURSOR, THM (pre-CURSE-or) PRECURSOR, THM

Natural organic compounds found in all surface and groundwaters. These compounds *MAY* react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs); they *MUST* be present in order for THMs to form.

PRESCRIPTIVE (pre-SKRIP-tive) PRESCRIPTIVE

Water rights which are acquired by diverting water and putting it to use in accordance with specified procedures. These procedures include filing a request to use unused water in a stream, river or lake with a state agency.

PRESSURE CONTROL PRESSURE CONTROL

A switch which operates on changes in pressure. Usually this is a diaphragm pressing against a spring. When the force on the diaphragm overcomes the spring pressure, the switch is actuated (activated).

PRESSURE HEAD PRESSURE HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

PRESTRESSED PRESTRESSED

A prestressed pipe has been reinforced with wire strands (which are under tension) to give the pipe an active resistance to loads or pressures on it.

PRIMARY ELEMENT PRIMARY ELEMENT

An instrument which measures (senses) a physical condition or variable of interest. Floats and thermocouples are examples of primary elements. Also called a SENSOR.

PRIME PRIME

The action of filling a pump casing with water to remove the air. Most pumps must be primed before startup or they will not pump any water.

PROCESS VARIABLE PROCESS VARIABLE

A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or an industrial plant.

PRODUCT WATER PRODUCT WATER

Water that has passed through a water treatment plant. All the treatment processes are completed or finished. This water is the product from the water treatment plant and is ready to be delivered to the consumers. Also called FINISHED WATER.

PROFILE PROFILE

A drawing showing elevation plotted against distance, such as the vertical section or side view of a pipeline.

PRUSSIAN BLUE PRUSSIAN BLUE

A blue paste or liquid (often on a paper like carbon paper) used to show a contact area. Used to determine if gate valve seats fit properly.

PSIG PSIG

Pounds per **S**quare **I**nch **G**age pressure. The pressure within a closed container or pipe measured with a gage in pounds per square inch. See GAGE PRESSURE.

PUMPING WATER LEVEL PUMPING WATER LEVEL

The vertical distance in feet from the centerline of the pump discharge to the level of the free pool while water is being drawn from the pool.

PURVEYOR, WATER (purr-VAY-or) PURVEYOR, WATER

An agency or person that supplies water (usually potable water).

PUTREFACTION (PEW-truh-FACK-shun) PUTREFACTION

Biological decomposition of organic matter, with the production of ill-smelling and tasting products, associated with anaerobic (no oxygen present) conditions.

QUICKLIME QUICKLIME

A material that is mostly calcium oxide (CaO) or calcium oxide in natural association with a lesser amount of magnesium oxide. Quicklime is capable of combining with water, that is, becoming slaked. Also see HYDRATED LIME.

RADIAL TO IMPELLER RADIAL TO IMPELLER

Perpendicular to the impeller shaft. Material being pumped flows at a right angle to the impeller.

RADICAL RADICAL

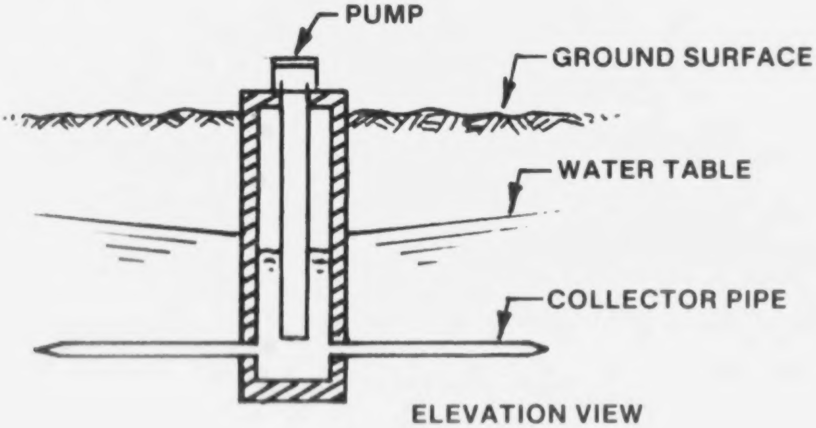
A group of atoms that is capable of remaining unchanged during a series of chemical reactions. Such combinations (radicals) exist in the molecules of many organic compounds; sulfate (SO_4^{2-}) is an inorganic radical.

RANGE RANGE

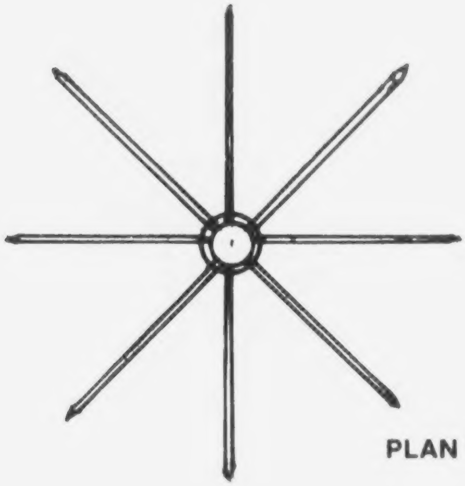
The spread from minimum to maximum values that an instrument is designed to measure. Also see SPAN and EFFECTIVE RANGE.

RANNEY COLLECTOR RANNEY COLLECTOR

This water collector is constructed as a dug well from 12 to 16 feet (3.5 to 5 m) in diameter that has been sunk as a caisson near the bank of a river or lake. Screens are driven radially and approximately horizontally from this well into the sand and the gravel deposits underlying the river.



ELEVATION VIEW



PLAN VIEW OF COLLECTOR PIPES

RANNEY COLLECTOR

RAW WATER RAW WATER

(1) Water in its natural state, prior to any treatment.

(2) Usually the water entering the first treatment process of a water treatment plant.

REAERATION (RE-air-A-shun) REAERATION

The introduction of air through forced air diffusers into the lower layers of the reservoir. As the air bubbles form and rise through the water, oxygen from the air dissolves into the water and replenishes the dissolved oxygen. The rising bubbles also cause the lower waters to rise to the surface where oxygen from the atmosphere is transferred to the water. This is sometimes called surface reaeration.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

RECARBONATION (re-CAR-bun-NAY-shun) RECARBONATION

A process in which carbon dioxide is bubbled into the water being treated to lower the pH. The pH may also be lowered by the addition of acid. Recarbonation is the final stage in the lime-soda ash softening process. This process converts carbonate ions to bicarbonate ions and stabilizes the solution against the precipitation of carbonate compounds.

RECEIVER RECEIVER

A device which indicates the result of a measurement. Most receivers in the water utility field use either a fixed scale and movable indicator (pointer) such as pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called an INDICATOR.

RECORDER RECORDER

A device that creates a permanent record, on a paper chart or magnetic tape, of the changes of some measured variable.

REDUCING AGENT REDUCING AGENT

Any substance, such as base metal (iron) or the sulfide ion (S^{2-}) that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

REFERENCE REFERENCE

A physical or chemical quantity whose value is known exactly, and thus is used to calibrate or standardize instruments.

RELIQUEFACTION (re-LICK-we-FACK-shun) RELIQUEFACTION

The return of a gas to the liquid state; for example, a condensation of chlorine gas to return it to its liquid form by cooling.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

RESIDUAL CHLORINE RESIDUAL CHLORINE

The amount of free and/or available chlorine remaining after a given contact time under specified conditions.

RESIDUE RESIDUE

The dry solids remaining after the evaporation of a sample of water or sludge. Also see TOTAL DISSOLVED SOLIDS.

RESPIRATION RESPIRATION

The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.

REVERSE OSMOSIS (oz-MOE-sis) REVERSE OSMOSIS

The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). The liquid produced is a demineralized water. Also see OSMOSIS.

RIPARIAN (ri-PAIR-ee-an) RIPARIAN

Water rights which are acquired together with title to the land bordering a source of surface water. The right to put to beneficial use surface water adjacent to your land.

RODENTICIDE (row-DENT-uh-SIDE) RODENTICIDE

Any substance or chemical used to kill or control rodents.

ROTAMETER (RODE-uh-ME-ter) ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.

ROTOR ROTOR

The rotating part of a machine. The rotor is surrounded by the stationary (non-moving) parts (stator) of the machine.

SACRIFICIAL ANODE SACRIFICIAL ANODE

An easily corroded material deliberately installed in a pipe or tank. The intent of such an installation is to give up (sacrifice) this anode to corrosion while the water supply facilities remain relatively corrosion free.

SAFE DRINKING WATER ACT SAFE DRINKING WATER ACT

Commonly referred to as SDWA. An Act passed by the U.S. Congress in 1974. The Act establishes a cooperative program among local, state and federal agencies to insure safe drinking water for consumers.

SAFE WATER SAFE WATER

Water that does not contain harmful bacteria, or toxic materials or chemicals. Water may have taste and odor problems, color and certain mineral problems and still be considered safe for drinking.

SAFE YIELD SAFE YIELD

The annual quantity of water that can be taken from a source of supply over a period of years without depleting the source permanently (beyond its ability to be replenished naturally in "wet years").

SALINITY SALINITY

(1) The relative concentration of dissolved salts, usualy sodium chloride, in a given water.

(2) A measure of the concentration of dissolved mineral substances in water.

SANITARY SURVEY SANITARY SURVEY

A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, treatment and distribution facilities to insure its protection from all pollution sources.

SAPROPHYTES (SAP-row-FIGHTS) SAPROPHYTES

Organisms living on dead or decaying organic matter. They help natural decomposition of organic matter in water.

SATURATION SATURATION

The condition of a liquid (water) when it has taken into solution the maximum possible quantity of a given substance at a give temperature and pressure.

SATURATOR (SAT-you-RAY-tore) SATURATOR

A device which produces a fluoride solution for the fluoridation process. The device is usually a cylindrical container with granular sodium fluoride on the bottom. Water flows either upward or downward through the sodium fluoride to produce the fluoride solution.

SCFM SCFM

Cubic **F**eet of air per **M**inute at **S**tandard conditions of temperature, pressure and humidity (0°C / 14.7 psia / 50% relative humidity).

SDWA SDWA

See **SAFE DRINKING WATER ACT**.

SCHEDULE, PIPE SCHEDULE, PIPE

A sizing system of arbitrary numbers that specifies the I.D. (inside diameter) and O.D. (outside diameter) for each diameter pipe. This term is used for steel, wrought iron and some types of plastic pipe. Also used to describe the strength of some types of plastic pipe.

SECCHI DISC (SECK-key) SECCHI DISC

A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.

SEDIMENTATION (SED-uh-men-TAY-shun) SEDIMENTATION

A water treatment process in which solid particles settle out of the water being treated in a large clarifier or sedimentation basin.

SEIZE UP SEIZE UP

Seize up occurs when an engine overheats and a part expands to the point where the engine will not run. Also called "freezing."

SENSOR SENSOR

An instrument that measure (senses) a physical condition or variable of interest. Floats and thermocouples are examples of sensors. Also called a PRIMARY ELEMENT.

SEPTIC (SEP-tick) SEPTIC

A condition produced by bacteria when all oxygen supplies are depleted. If severe, bottom deposits and water turn black, give off foul odors, and the water has a greatly increased chlorine demand.

SEQUESTRATION (SEE-kwes-TRAY-shun) SEQUESTRATION

A chemical complexing (forming or joining together) of metallic cations (such as iron) with certain inorganic compounds, such as phosphate. Sequestration prevents the precipitation of the metals (iron). Also see CHELATION.

SERVICE PIPE SERVICE PIPE

The pipeline extending from the water main to the building served or to the consumer's system.

SET POINT SET POINT

The position at which the control or controller is set. This is the same as the desired value of the process variable.

SEWAGE SEWAGE

The used water and solids that flow from homes through sewers to a wastewater treatment plant. The preferred term is WASTEWATER.

SHOCK LOAD SHOCK LOAD

The arrival at a water treatment plant of raw water containing unusual amounts of algae, colloidal matter, color, suspended solids, turbidity, or other pollutants.

SHORT-CIRCUITING SHORT-CIRCUITING

A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

SIMULATE SIMULATE

To reproduce the action of some process, usually on a smaller scale.

SINGLE-STAGE PUMP SINGLE-STAGE PUMP

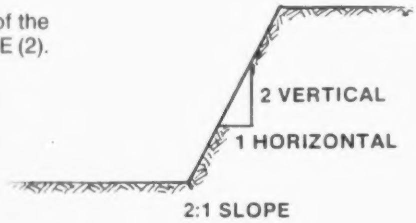
A pump that has only one impeller. A multi-stage pump has more than one impeller.

SLAKE SLAKE

To mix with water with a true chemical combination (hydrolysis) taking place, such as in the slaking of lime.

SLOPE SLOPE

The slope or inclination of a trench bottom or a trench side wall is the ratio of the vertical distance to the horizontal distance or "rise over run." Also see GRADE (2).



SLUDGE (sluj) SLUDGE

The settleable solids separated from water during processing.

SLURRY (SLUR-e) SLURRY

A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SMCLs SMCLs

Secondary **M**aximum **C**ontaminant **L**evel**s**. Secondary MCLs for various water quality indicators are established to protect public welfare.

SNARL SNARL

Suggested **N**o **A**dverse **R**esponse **L**evel. The concentration of a chemical in water that is expected not to cause an adverse health effect.

SOFTWARE PROGRAMS SOFTWARE PROGRAMS

Computer programs; the list of instructions that tell a computer how to perform a given task or tasks.

SOFT WATER SOFT WATER

Water having a low concentration of calcium and magnesium ions. According to U.S. Geological Survey guidelines, soft water is water having a hardness of 60 milligrams per liter or less.

SOLENOID (SO-luh-noid) SOLENOID

A magnetically (electrical coil) operated mechanical device. Solenoids can operate a small valve or a larger switch.

SOLUTION SOLUTION

A liquid mixture of dissolved substances. In a solution it is impossible to see all the separate parts.

SOUNDING TUBE SOUNDING TUBE

A pipe or tube used for measuring the depths of water.

SPAN SPAN

The scale or range of values an instrument is designed to measure. Also see RANGE.

SPECIFIC CONDUCTANCE SPECIFIC CONDUCTANCE

A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called CONDUCTANCE.

SPECIFIC GRAVITY SPECIFIC GRAVITY

Weight of a particle, substance, or chemical solution in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (39°F). Particulates in raw water may have a specific gravity of 1.005 to 2.5.

SPECIFIC YIELD SPECIFIC YIELD

The quantity of water that a unit volume of saturated permeable rock or soil will yield when drained by gravity. Specific yield may be expressed as a ratio or as a percentage by volume.

SPOIL SPOIL

Excavated material such as soil from the trench of a water main.

SPORE SPORE

The reproductive body of an organism which is capable of giving rise to a new organism either directly or indirectly. A viable (able to live and grow) body regarded as the resting stage of an organism. A spore is usually more resistant to disinfectants and heat than most organisms.

SPRING LINE SPRING LINE

Theoretical center of a pipeline. Also, the guideline for laying a course of bricks.

STALE WATER STALE WATER

Water which has not flowed recently and may have picked up tastes and odors from distribution lines or storage facilities.

STANDARD STANDARD

A physical or chemical quantity whose value is known exactly, and is used to calibrate or standardize instruments. Also see REFERENCE.

STANDARD METHODS STANDARD METHODS

STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. A joint publication of the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation which outlines the procedures used to analyze the impurities in water and wastewater.

STANDARD SOLUTION STANDARD SOLUTION

A solution in which the exact concentration of a chemical or compound is known.

STANDARDIZE STANDARDIZE

To compare with a standard.

(1) In wet chemistry, to find out the exact strength of a solution by comparing it with a standard of known strength.

(2) To set up an instrument or device to read a standard. This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

STARTERS STARTERS

Devices used to start up large motors gradually to avoid severe mechanical shock to a driven machine and to prevent disturbance to the electrical lines (causing dimming and flickering of lights).

STATIC HEAD STATIC HEAD

When water is not moving, the vertical distance (in feet) from a specific point to the water surface is the static head. (The static pressure in psi is the static head in feet times 0.433 psi/ft.) Also see DYNAMIC PRESSURE and STATIC PRESSURE.

STATIC PRESSURE STATIC PRESSURE

When water is not moving, the vertical distance (in feet) from a specific point to the water surface is the static head. The static pressure in psi is the static head in feet times 0.433 psi/ft. Also see DYNAMIC PRESSURE and STATIC HEAD.

STATIC WATER DEPTH STATIC WATER DEPTH

The vertical distance in feet from the centerline of the pump discharge down to the surface level of the free pool while no water is being drawn from the pool or water table.

STATIC WATER LEVEL STATIC WATER LEVEL

(1) The elevation or level of the water table in a well when the pump is not operating.

(2) The level or elevation to which water would rise in a tube connected to an artesian aquifer, or basin, or conduit under pressure.

STATOR STATOR

That portion of a machine which contains the stationary (non-moving) parts that surround the moving parts (rotor).

STERILIZATION (STARE-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

STETHOSCOPE STETHOSCOPE

An instrument used to magnify sounds and convey them to the ear.

STRATIFICATION (STRAT-uh-fuh-KAY-shun) STRATIFICATION

The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature. Also see THERMAL STRATIFICATION.

SUBMERGENCE SUBMERGENCE

The distance between the water surface and the media surface in a filter.

SUBSIDENCE (sub-SIDE-ence) SUBSIDENCE

The dropping or lowering of the ground surface as a result of removing excess water (overdraft or over pumping) from an aquifer. After excess water has been removed, the soil will settle, become compacted and the ground surface will drop.

SUCTION LIFT SUCTION LIFT

The *NEGATIVE* pressure [in feet (meters) of water or inches (centimeters) of mercury vacuum] on the suction side of the pump. The pressure can be measured from the centerline of the pump *DOWN TO* (lift) the elevation of the hydraulic grade line on the suction side of the pump.

SUPERCHLORINATION (SUE-per-KLOR-uh-NAY-shun) SUPERCHLORINATION

Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

SUPERSATURATED SUPERSATURATED

An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation concentration for the substance.

SURFACE LOADING SURFACE LOADING

One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called OVERFLOW RATE.

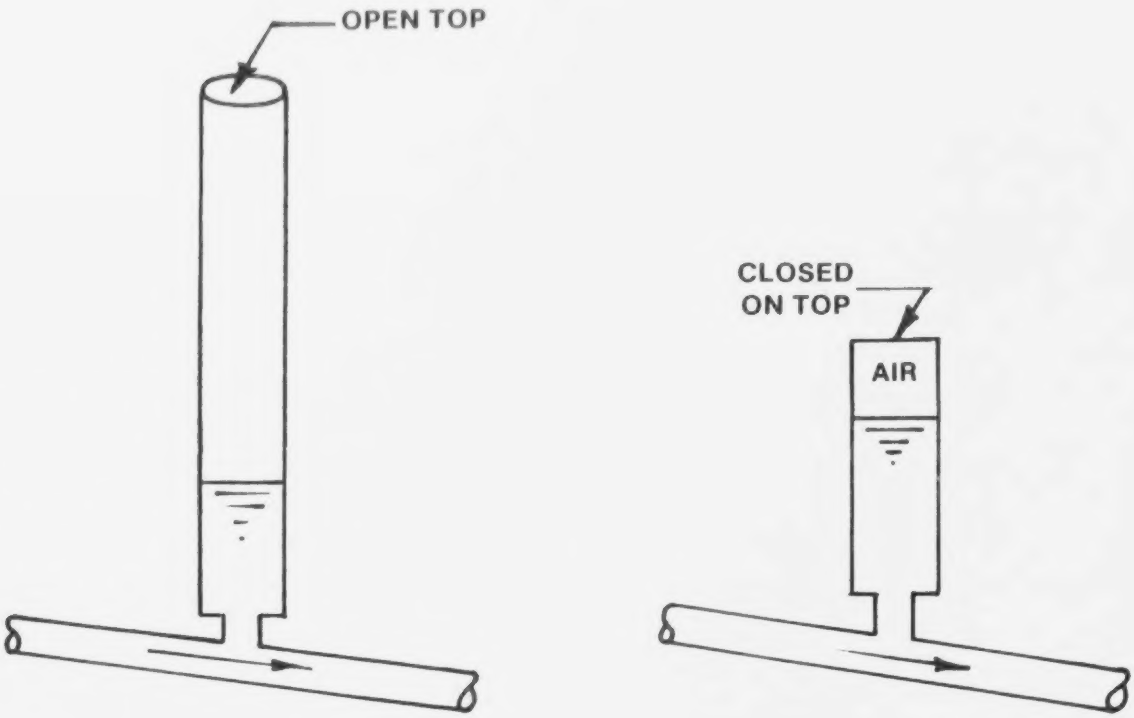
$$\text{Surface Loading, GPD/sq ft} = \frac{\text{Flow, gallon/day}}{\text{Surface Area, sq ft}}$$

SURFACTANT (sir-FAC-tent) SURFACTANT

Abbreviation for surface-active agent. The active agent in detergents that possesses a high cleaning ability.

SURGE CHAMBER SURGE CHAMBER

A chamber or tank connected to a pipe and located at or near a valve that may quickly open or close or a pump that may suddenly start or stop. When the flow of water in a pipe starts or stops quickly, the surge chamber allows water to flow into or out of the pipe and minimize any sudden positive or negative pressure waves or surges in the pipe.



TYPES OF SURGE CHAMBERS

SURGE CHAMBER

SUSPENDED SOLIDS SUSPENDED SOLIDS

(1) Solids that either float on the surface or are suspended in water or other liquids, and which are largely removable by laboratory filtering.

(2) The quantity of material removed from water in a laboratory test, as prescribed in *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER* and referred to as nonfilterable residue.

TAILGATE SAFETY MEETING TAILGATE SAFETY MEETING

The term *TAILGATE* comes from the safety meetings regularly held by the construction industry around the tailgate of a truck.

TCE TCE

See TRICHLOROETHANE.

TDS TDS

See TOTAL DISSOLVED SOLIDS.

TELEMETRY (tel-LEM-uh-tree) TELEMETRY

The electrical link between the transmitter and the receiver. Telephone lines are commonly used to serve as the electrical line.

TEMPERATURE SENSOR TEMPERATURE SENSOR

A device that opens and closes a switch in response to changes in the temperature. This device might be a metal contact, or a thermocouple that generates minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a HEAT SENSOR.

THERMAL STRATIFICATION (STRAT-uh-fuh-KAY-shun) THERMAL STRATIFICATION

The formation of layers of different temperatures in a lake or reservoir. Also see STRATIFICATION.

THERMOCLINE (THUR-moe-KLINE) THERMOCLINE

The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the METALIMNION.

THERMOCOUPLE THERMOCOUPLE

A heat-sensing device made of two conductors of different metals joined at their ends. An electric current is produced when there is a difference in temperature between the ends.

THM THM

See TRIHALOMETHANES.

THM PRECURSOR THM PRECURSOR

See PRECURSOR, THM.

THRESHOLD ODOR THRESHOLD ODOR

The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called ODOR THRESHOLD.

THRESHOLD ODOR NUMBER THRESHOLD ODOR NUMBER

TON. The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.

THRUST BLOCK THRUST BLOCK

A mass of concrete or similar material appropriately placed around a pipe to prevent movement when the pipe is carrying water. Usually placed at bends and valve structures.

TIME LAG TIME LAG

The time required for processes and control systems to respond to a signal or to reach a desired level.

TIMER TIMER

A device for automatically starting or stopping a machine or other device at a given time.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point.

TOPOGRAPHY TOPOGRAPHY

The arrangement of hills and valleys in a geographic area.

TOTAL DISSOLVED SOLIDS (TDS) TOTAL DISSOLVED SOLIDS (TDS)

All of the dissolved solids in a water. TDS is measured on a sample of water that has passed through a very fine mesh filter to remove suspended solids. The water passing through the filter is evaporated and the residue represents the dissolved solids. Also see SPECIFIC CONDUCTANCE.

TOTAL DYNAMIC HEAD (TDH) TOTAL DYNAMIC HEAD (TDH)

When a pump is lifting or pumping water, the vertical distance (in feet) from the elevation of the energy grade line on the suction side of the pump to the elevation of the energy grade line on the discharge side of the pump.

TOTAL RESIDUAL CHLORINE TOTAL RESIDUAL CHLORINE

The amount of available chlorine remaining after a given contact time. The sum of the combined available residual chlorine and the free available residual chlorine. Also see RESIDUAL CHLORINE.

TOTALIZER TOTALIZER

A device or meter that continuously measures and calculates (adds) total flows in gallons, million gallons, cubic feet, or some other unit of volume measurement. Also called an INTEGRATOR.

TOXAPHENE (TOX-uh-FEEN) TOXAPHENE

A chemical that causes adverse health effects in domestic water supplies and also is toxic to freshwater and marine aquatic life.

TOXIC (TOX-ick) TOXIC

A substance which is poisonous to an organism.

TRANSDUCER (trans-DUE-sir) TRANSDUCER

A device which senses some varying condition and converts it to an electrical signal for transmission to some other device (a receiver) for processing or decision making.

TRANSMISSION LINES TRANSMISSION LINES

Pipelines that transport raw water from its source to a water treatment plant. After treatment, water is usually pumped into pipelines (transmission lines) that are connected to a distribution grid system.

TRANSMISSIVITY (TRANS-miss-SIV-it-tee) TRANSMISSIVITY

A measure of the ability to transmit (as in the ability of an aquifer to transmit water).

TRANSPIRATION (TRAN-spur-RAY-shun) TRANSPIRATION

The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.

TREMIE (TREH-me) TREMIE

A device used to place concrete or grout under water.

TRICHLOROETHANE (TCE) (try-KLOR-o-ETH-hane) TRICHLOROETHANE (TCE)

An organic chemical used as a cleaning solvent that causes adverse health effects in domestic water supplies.

TRIHALOMETHANES (tri-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

TUBE SETTLER TUBE SETTLER

A device that uses bundles of small bore (2 to 3 inches or 50 to 75 mm) tubes installed on an incline as an aid to sedimentation. The tubes may come in a variety of shapes including circular and rectangular. As water rises within the tubes, settling solids fall to the tube surface. As the sludge (from the settled solids) in the tube gains weight, it moves down the tubes and settles to the bottom of the basin for removal by conventional sludge collection means. Tube settlers are sometimes installed in sedimentation basins and clarifiers to improve particle removal.

TUBERCLE (TOO-burr-cull) TUBERCLE

A protective crust of corrosion products (rust) which builds up over a pit caused by the loss of metal due to corrosion.

TUBERCULATION (too-BURR-que-LAY-shun) TUBERCULATION

The development of formation of small mounds of corrosion products (rust) on the inside of iron pipe. These mounds (tubercules) increase the roughness of the inside of the pipe thus increasing resistance to water flow (decreases the C Factor).

TURBID TURBID

Having a cloudy or muddy appearance.

TURBIDIMETER TURBIDIMETER

See TURBIDITY METER.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY METER TURBIDITY METER

An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.

TURBIDITY UNITS (TU) TURBIDITY UNITS (TU)

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water. They are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

TURN-DOWN RATIO TURN-DOWN RATIO

The ratio of the design range to the range of acceptable accuracy or precision of an instrument. Also see EFFECTIVE RANGE.

UNCONSOLIDATED FORMATION UNCONSOLIDATED FORMATION

A sediment that is loosely arranged or unstratified (not in layers) or whose particles are not cemented together (soft rock); occurring either at the ground surface or at a depth below the surface. Also see CONSOLIDATED FORMATION.

UNIFORMITY COEFFICIENT (U.C.) UNIFORMITY COEFFICIENT (U.C.)

The ratio of (1) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through.

$$\text{Uniformity Coefficient} = \frac{\text{Particle Diameter}_{60\%}}{\text{Particle Diameter}_{10\%}}$$

VARIABLE FREQUENCY DRIVE VARIABLE FREQUENCY DRIVE

A control system that allows the frequency of the current applied to a motor to be varied. The motor is connected to a low-frequency source while standing still; the frequency is then increased gradually until the motor and pump (or other driven machine) is at the desired speed.

VARIABLE, MEASURED VARIABLE, MEASURED

A factor (flow, temperature) that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

VARIABLE, PROCESS VARIABLE, PROCESS

A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or an industrial plant.

VELOCITY HEAD VELOCITY HEAD

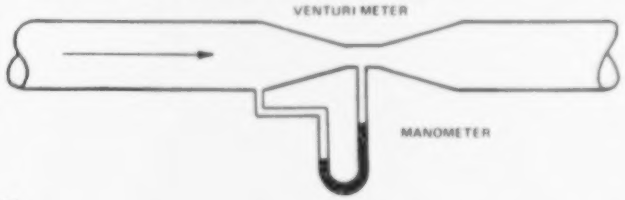
The energy in flowing water as determined by a vertical height (in feet or meters) equal to the square of the velocity of flowing water divided by twice the acceleration due to gravity ($V^2/2g$).

VENTURI METER VENTURI METER

A flow measuring device placed in a pipe. The device consists of a tube whose diameter gradually decreases to a throat and then gradually expands to the diameter of the pipe. The flow is determined on the basis of the differences in pressure (caused by different velocity heads) between the antrance and throat of the Venturi meter.

[SEE DRAWING ON PAGE 515]

NOTE: Most Venturi meters have pressure sensing taps rather than a manometer to measure the pressure difference. The upstream tap is the high pressure tap or side of the monometer.



VISCOSITY (vis-KOSS-uh-tee) VISCOSITY

A property of water, or any other fluid, which resists efforts to change its shape or flow. Syrup is more viscous (has a higher viscosity) than water. The viscosity of water increases significantly as temperatures decrease. Motor oil is rated by how thick (viscous) it is; 20 weight oil is considered relatively thin while 50 weight oil is relatively thick or viscous.

VOID VOID

A pore or open space in rock, soil or other granular material, not occupied by solid matter. The pore or open space may be occupied by air, water, or other gaseous or liquid material. Also called a void space or interstice.

VOLATILE (VOL-uh-tull) VOLATILE

A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.

VOLATILE ACIDS VOLATILE ACIDS

Acids produced during digestion. Fatty acids which are soluble in water and can be steam-distilled at atmospheric pressure. Also called "organic acids." Volatile acids are commonly reported as equivalent to acetic acid.

VOLATILE LIQUIDS VOLATILE LIQUIDS

Liquids which easily vaporize or evaporate at room temperatures.

VOLATILE SOLIDS VOLATILE SOLIDS

Those solids in water or other liquids that are lost on ignition of the dry solids at 550°C.

VOLTAGE VOLTAGE

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See ELECTROMOTIVE FORCE (E.M.F.).

VOLUMETRIC VOLUMETRIC

A measurement based on the volume of some factor. Volumetric titration is a means of measuring unknown concentrations of water quality indicators in a sample by determining the volume of titrant or liquid reagent needed to complete particular reactions.

VORTEX VORTEX

A revolving mass of water which forms a whirlpool. This whirlpool is caused by water flowing out of a small opening in the bottom of a basin or reservoir. A funnel-shaped opening is created downward from the water surface.

WASTEWATER WASTEWATER

The used water and solids from a community (including used water from industrial processes) that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a wastewater treatment plant. The term "sewage" usually refers to household wastes, but this word is being replaced by the term "wastewater."

WATER AUDIT WATER AUDIT

A thorough examination of the accuracy of water agency records or accounts (volumes of water) and system control equipment. Water managers can use audits to determine their water distribution system efficiency. The overall goal is to identify and verify water and revenue losses in a water system.

WATER HAMMER WATER HAMMER

The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.

WATER PURVEYOR (purr-VAY-or) WATER PURVEYOR

An agency or person that supplies water (usually potable water).

WATER TABLE WATER TABLE

The upper surface of the zone of saturation of groundwater in an unconfined aquifer.

WATT WATT

A unit of power equal to one joule per second. The power of a current of one ampere flowing across a potential difference of one volt.

WEIR (weer) WEIR

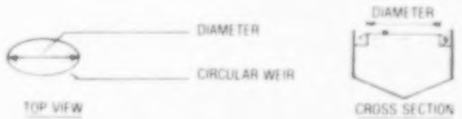
(1) A wall or plate placed in an open channel and used to measure the flow of water. The depth of the flow over the weir can be used to calculate the flow rate, or a chart or conversion table may be used.

(2) A wall or obstruction used to control flow (from settling tanks and clarifiers) to assure uniform flow rate and avoid short-circuiting.

WEIR DIAMETER (weer) WEIR DIAMETER

Many circular clarifiers have a circular weir within the outside edge of the clarifier. All the water leaving the clarifier flows over this weir. The diameter of the weir is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.

WEIR DIAMETER



WEIR LOADING WEIR LOADING

A guideline used to determine the length of weir needed on settling tanks and clarifiers in treatment plants. Used by operators to determine if weirs are hydraulically (flow) overloaded.

$$\text{Weir Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Length of Weir, ft}}$$

WELL LOG WELL LOG

A record of the thickness and characteristics of the soil, rock and water-bearing formations encountered during the drilling (sinking) of a well.

WET CHEMISTRY WET CHEMISTRY

Laboratory procedures used to analyze a sample of water using liquid chemical solutions (wet) instead of, or in addition to, laboratory instruments.

WHOLESOME WATER WHOLESOME WATER

A water that is safe and palatable for human consumption.

WIRE-TO-WATER EFFICIENCY WIRE-TO-WATER EFFICIENCY

The efficiency of a pump and motor together. Also called the OVERALL EFFICIENCY.

YIELD YIELD

The quantity of water (expressed as a rate of flow — GPM, GPH, GPD, or total quantity per year) that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic considerations. Also see SAFE YIELD.

ZEOLITE ZEOLITE

A type of ion exchange material used to soften water. Natural zeolites are siliceous compounds (made of silica) which remove calcium and magnesium from hard water and replace them with sodium. Synthetic or organic zeolites are ion exchange materials which remove calcium or magnesium and replace them with either sodium or hydrogen.

ZETA POTENTIAL ZETA POTENTIAL

In coagulation and flocculation procedures, the difference in the electrical charge between the dense layer of ions surrounding the particle and the charge of the bulk of the suspended fluid surrounding this particle. The zeta potential is usually measured in millivolts.

ZONE OF AERATION ZONE OF AERATION

The comparatively dry soil or rock located between the ground surface and the top of the water table.

ZONE OF SATURATION ZONE OF SATURATION

The soil or rock located below the top of the groundwater table. By definition, the zone of saturation is saturated with water. Also see WATER TABLE.

ZOOPLANKTON (ZOE-PLANK-ton) ZOOPLANKTON

Small, usually microscopic animals (such as protozoans), found in lakes and reservoirs.

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INTERIM PRIMARY DRINKING WATER REGULATIONS

INORGANIC CHEMICALS	ARSENIC	0.05 mg/L	FOR ALL INORGANIC CONTAMINANTS LISTED SURFACE WATERS EVERY YEAR GROUNDWATERS EVERY 3 YEARS	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	FOR ALL INORGANIC CONTAMINANTS LISTED EXCEPT NITRATE IF ANY CONTAMINANT EXCEEDS THE MCL THIS MUST BE REPORTED TO THE STATE WITHIN 7 DAYS AND THREE ADDITIONAL SAMPLES (CALLED CHECK SAMPLES) MUST BE TAKEN WITHIN ONE MONTH	FOR ALL INORGANIC CONTAMINANTS LISTED EXCEPT NITRATE NOTIFY STATE WITHIN 7 DAYS IF MCL IS EXCEEDED AND INITIATE CHECK SAMPLING WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES STILL EXCEEDS THE MCL THIS MUST BE REPORTED TO THE STATE WITHIN 48 HRS	FOR ALL INORGANIC CONTAMINANTS LISTED EXCEPT NITRATE WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES EXCEEDS THE MCL, THE PUBLIC MUST BE NOTIFIED
	BARIUM	1. mg/L					
	CADMIUM	0.010 mg/L					
	CHROMIUM	0.05 mg/L					
	LEAD	0.05 mg/L					
	MERCURY	0.002 mg/L					
	SELENIUM	0.01 mg/L					
	SILVER	0.05 mg/L					
	SODIUM						
	FLUORIDE (AVERAGE ANNUAL AIR TEMPERATURES) — °F a. 53.7 & BELOW b. 53.8-58.3 c. 58.4-63.8 d. 63.9-70.6 e. 70.7-79.2 f. 79.3-90.5	a. 2.4 mg/L b. 2.2 mg/L c. 2.0 mg/L d. 1.8 mg/L e. 1.6 mg/L f. 1.4 mg/L					
	NITRATE (AS N)	10 mg/L			FOR NITRATE ONLY: WHEN THE CONCENTRATION EXCEEDS THE MCL, A CHECK SAMPLE MUST BE TAKEN WITHIN 24 HRS.	FOR NITRATE ONLY IF THE AVERAGE OF THE ORIGINAL SAMPLE AND THE CHECK SAMPLE EXCEEDS THE MCL, REPORT TO THE STATE WITHIN 48 HRS.	FOR NITRATE ONLY WHEN THE AVERAGE OF THE ORIGINAL AND THE CHECK SAMPLE EXCEEDS THE MCL, THE PUBLIC MUST BE NOTIFIED
ORGANIC CHEMICALS	CHLORINATED HYDROCARBONS PESTICIDES		SURFACE WATERS EVERY 3 YEARS STATE OPTION FOR GROUNDWATERS	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	ANY CONTAMINANT EXCEEDING MCL MUST BE REPORTED TO STATE WITHIN 7 DAYS AND THREE ADDITIONAL (CHECK) SAMPLES TO BE TAKEN WITHIN ONE MONTH	WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES STILL EXCEEDS THE MCL. THIS MUST BE REPORTED TO THE STATE WITHIN 48 HRS	WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES STILL EXCEEDS THE MCL, THE PUBLIC MUST BE NOTIFIED
	ENDRIN	0.0002 mg/L					
	LINDANE	0.004 mg/L					
	METHOXYCHLOR	0.1 mg/L					
	TOXAPHENE	0.005 mg/L					
	CHLOROPHENOXYS HERBICIDES						
	2,4,5-TP (SILVEX)	0.01 mg/L					
	2,4-D	0.1 mg/L					
	TOTAL TRIHALOMETHANES	0.10 mg/L	QUARTERLY CHLORINATED SURFACE AND GROUNDWATERS	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	AT LEAST ONE CHECK SAMPLE TO CONFIRM RESULTS OF REDUCED MONITORING SAMPLING VIOLATION	WHEN RUNNING ANNUAL AVERAGE EXCEEDS MCL REPORT TO STATE WITHIN 48 HRS	AVERAGE OF ANY 12 MO. WHICH EXCEEDS MCL MUST NOTIFY PUBLIC

TURBIDITY	TURBIDITY	1 TU MONTHLY AVERAGE (5 TU MONTHLY AVERAGE MAY APPLY AT STATE OPTION PROVIDED IT DOES NOT INTERFERE WITH 1 DISINFECTION 2 MAINTENANCE OF EFFECTIVE Cl_2 RESIDUAL 3 BACTERIOLOGICAL TESTS) OR 5 TU AVG. OF 2 CONSECUTIVE DAYS	SAMPLE SURFACE WATERS DAILY	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	IF A TURBIDITY SAMPLE EXCEEDS 1 TU, CHECK SAMPLE WITHIN 1 HR. IF CHECK SAMPLE CONFIRMS THE MCL IS EXCEEDED, REPORT TO THE STATE WITHIN 48 HRS	USING THE CHECK SAMPLE TO CALCULATE AN AVERAGE, IF THE MONTHLY AVERAGE OF 1 TU OR 2-DAY AVERAGE OF 5 TU IS EXCEEDED, REPORT TO THE STATE WITHIN 48 HRS	WHEN MONTHLY AVERAGE 1 TU OR 2-DAY AVERAGE OF 5 TU IS EXCEEDED, THE PUBLIC MUST BE NOTIFIED
MICRO-BIOLOGICAL CONTAMINANTS	COLIFORM BACTERIA	MEMBRANE FILTER COLIFORM SHALL NOT EXCEED 1 PER 100 mL FOR THE AVERAGE OF ALL MONTHLY SAMPLES, OR 4 PER 100 mL IN MORE THAN ONE SAMPLE IF LESS THAN 20 SAMPLES COLLECTED PER MONTH, OR 4 PER 100 mL IN MORE THAN 5% OF SAMPLES IF 20 OR MORE SAMPLES EXAMINED PER MONTH FERMENTATION TUBE — 10 mL PORTION* COLIFORMS SHALL NOT BE PRESENT IN MORE THAN 10% OF PORTIONS PER MONTH. NOT MORE THAN 1 SAMPLE MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN LESS THAN 20 SAMPLES ARE EXAMINED PER MONTH, OR NOT MORE THAN 5% OF SAMPLES MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN 20 OR MORE SAMPLES ARE EXAMINED PER MONTH *IF 100 mL PORTIONS ARE USED, SEE REGULATIONS, PAGE 59571	THE TOTAL NUMBER OF SAMPLES ARE BASED ON THE POPULATION TABLE. FOR EXAMPLE:** POPULATION SERVED — MINIMUM NUMBER OF SAMPLES PER MONTH 25 to 1,000 — 1 1,001 to 2,500 — 2 2,501 to 3,300 — 3 ** THE ENTIRE POPULATION TABLE IS IN THE MANUAL CHLORINE RESIDUAL SUBSTITUTION • STATE APPROVAL • 75% OF THE REQUIRED COLIFORM TESTS MAY BE SUBSTITUTED • FOR EACH COLIFORM TEST TO BE SUBSTITUTED, 4 Cl_2 RESIDUAL TESTS MUST BE CONDUCTED, BUT AT LEAST 1 Cl_2 TEST PER DAY • MINIMUM FREE RESIDUAL 0.2 mg/L • METHOD DPD	MUST BE FOLLOWED BY TWO CONSECUTIVE NEGATIVE CHECK SAMPLES UNDER CERTAIN CONDITIONS A SYSTEM TAKING 10 OR FEWER SAMPLES MAY EXCLUDE ONE POSITIVE ROUTINE FROM CALCULATIONS REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	MEMBRANE FILTER IF A SINGLE SAMPLE EXCEEDS 4 PER 100 mL, INITIATE AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES FROM SAME SAMPLING POINT. COLLECT ADDITIONAL SAMPLES DAILY OR AS DIRECTED BY THE STATE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW LESS THAN 1 PER 100 mL FERMENTATION TUBE — 10 mL PORTION* IF A SINGLE SAMPLE CONTAINS COLIFORM IN 3 OR MORE 10 mL PORTIONS, INITIATE CHECK SAMPLING AS ABOVE AND CONTINUE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW NO POSITIVE TUBES *IF 100 mL PORTIONS ARE USED, SEE REGULATIONS, PAGE 59571	MEMBRANE FILTER IF ANY MCL IS EXCEEDED, THE STATE MUST BE NOTIFIED IN 48 HRS. IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM, REPORT TO THE STATE WITHIN 48 HRS FERMENTATION TUBE IF ANY MCL IS EXCEEDED, THE STATE MUST BE NOTIFIED IN 48 HRS. IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM, REPORT TO THE STATE WITHIN 48 HRS CHLORINE RESIDUAL SUBSTITUTION IF DEFICIENT RESIDUAL IS CONFIRMED, REPORT TO STATE WITHIN 48 HRS AND COLLECT COLIFORM BACTERIA SAMPLE WITHIN 1 HR. REPORT BACTERIAL RESULTS TO STATE WITHIN 48 HRS. OF COMPLETION OF ANALYSIS	IF ANY MCL IS EXCEEDED, THE PUBLIC MUST BE NOTIFIED PUBLIC NOTICE DOES NOT APPLY TO DEFICIENT CHLORINE RESIDUAL SINCE THE RESIDUAL IS NOT A MAXIMUM CONTAMINANT LEVEL
RADIOLOGICAL CONTAMINANTS	NATURAL GROSS ALPHA COMBINED Ra-226 AND Ra-228 MAN-MADE GROSS BETA ACTIVITY TRITIUM STRONTIUM-90	NATURAL SCREENING: IF GROSS ALPHA EXCEEDS 5 pCi/L THEN TEST FOR Ra-226 IF Ra226 EXCEEDS 3pCi/L, TEST FOR Ra228 Ra226 + Ra228: 5pCi/L MAN MADE GROSS BETA: 50pCi/L TRITIUM: 20,000 pCi/L STRONTIUM 90: 8 pCi/L	EVERY 4 YEARS (COMPLIANCE WITH MCL BASED ON AVERAGE OF ANALYSIS OF FOUR CONSECUTIVE QUARTERS)	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	STATE OPTION STATE OPTION	WHEN THE ANNUAL AVERAGE MCL IS EXCEEDED, THIS MUST BE REPORTED TO THE STATE WITHIN 48 HRS	WHEN THE AVERAGE OF THE ORIGINAL EXCEEDS THE MCL, THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE
INORGANIC CHEMICALS	NITRATE (AS N)	10 mg/L MAY ALLOW UP TO 20 mg/L UNDER CONDITIONS WHERE NO ADVERSE HEALTH EFFECTS WILL RESULT	STATE OPTION	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	WHEN THE CONCENTRATION EXCEEDS THE MCL, A CHECK SAMPLE MUST BE TAKEN WITHIN 24 HRS	IF THE AVERAGE OF THE ORIGINAL SAMPLE AND THE CHECK SAMPLE EXCEEDS THE MCL, REPORT TO THE STATE WITHIN 48 HRS	WHEN THE AVERAGE OF THE ORIGINAL AND THE CHECK SAMPLE EXCEEDS THE MCL, THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE
TURBIDITY	TURBIDITY	STATE OPTION A. 1 TU MONTHLY AVERAGE (5 TU MONTHLY AVERAGE MAY APPLY AT STATE OPTION PROVIDED IT DOES NOT INTERFERE WITH 1. DISINFECTION 2. MAINTENANCE OF EFFECTIVE Cl_2 RESIDUAL 3. BACTERIOLOGICAL TESTS) OR B. 5 TU AVG. OF 2 CONSECUTIVE DAYS	SAMPLE SURFACE WATERS DAILY	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	IF A TURBIDITY SAMPLE EXCEEDS 1 TU, CHECK SAMPLE WITHIN 1 HR. IF CHECK SAMPLE CONFIRMS THE MCL IS EXCEEDED, REPORT TO THE STATE WITHIN 48 HRS	USING THE CHECK SAMPLE TO CALCULATE AN AVERAGE, IF THE MONTHLY AVERAGE OF 1 TU OR 2-DAY AVERAGE OF 5 TU IS EXCEEDED, REPORT TO THE STATE WITHIN 48 HRS	IF THE MONTHLY AVERAGE OF 1 TU OR THE 2-DAY AVERAGE OF 5 TU IS EXCEEDED, THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE
MICRO-BIOLOGICAL CONTAMINANTS	COLIFORM BACTERIA	MEMBRANE FILTER COLIFORM SHALL NOT EXCEED 1 PER 100 mL FOR THE AVERAGE OF ALL MONTHLY SAMPLES, OR 4 PER 100 mL IN MORE THAN ONE SAMPLE IF LESS THAN 20 SAMPLES COLLECTED PER MONTH, OR 4 PER 100 mL IN MORE THAN 5% OF SAMPLES IF 20 OR MORE SAMPLES EXAMINED PER MONTH FERMENTATION TUBE — 10 mL PORTION* COLIFORMS SHALL NOT BE PRESENT IN MORE THAN 10% OF PORTIONS PER MONTH. NOT MORE THAN 1 SAMPLE MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN LESS THAN 20 SAMPLES ARE EXAMINED PER MONTH, OR NOT MORE THAN 5% OF SAMPLES MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN 20 OR MORE SAMPLES ARE EXAMINED PER MONTH *IF 100 mL PORTIONS ARE USED, SEE REGULATIONS, PAGE 59571.	AT LEAST ONE SAMPLE PER QUARTER (THE STATE MAY SPECIFY AN ALTERNATE FREQUENCY ON THE BASIS OF A SANITARY SURVEY.)	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD, WHICHEVER IS SHORTER	MEMBRANE FILTER IF A SINGLE SAMPLE EXCEEDS 4 PER 100 mL, INITIATE AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES FROM SAME SAMPLING POINT. COLLECT ADDITIONAL SAMPLES DAILY OR AS DIRECTED BY THE STATE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW LESS THAN 1 PER 100 mL. FERMENTATION TUBE — 10 mL PORTION* IF A SINGLE SAMPLE CONTAINS COLIFORM IN 3 OR MORE 10 mL PORTIONS, INITIATE CHECK SAMPLING AS ABOVE AND CONTINUE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW NO POSITIVE TUBES *IF 100 mL PORTIONS ARE USED, SEE REGULATIONS, PAGE 59571	MEMBRANE FILTER IF ANY MCL IS EXCEEDED, THE STATE MUST BE NOTIFIED IN 48 HRS. IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM, REPORT TO THE STATE WITHIN 48 HRS FERMENTATION TUBE IF ANY MCL IS EXCEEDED, THE STATE MUST BE NOTIFIED IN 48 HRS. IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM, REPORT TO THE STATE WITHIN 48 HRS	IF ANY MCL IS EXCEEDED, THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE IF ANY MCL IS EXCEEDED, THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE

NOTE: CORROSIVITY MONITORING REQUIRED ACCORDING TO SECTION 141.42 OF NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

SECONDARY DRINKING WATER REGULATIONS (STATE OPTION)

NAME OF CONTAMINANT	SMCL	MONITORING REQUIREMENTS ROUTINE SAMPLING AND TESTING	RECOMMENDED ROUTINE REPORTING
CHLORIDE	250 mg/L	FOR ALL CONTAMINANTS LISTED STATE MAY DIRECT MORE FREQUENT MONITORING OF SPECIFIC PARAMETERS NO LESS FREQUENT THAN THE MONITORING PERFORMANCE FOR INORGANIC CHEMICALS CONTAMINANTS IN THE NIPDWR	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER
COLOR	15 COLOR UNITS		
COPPER	1 mg/L		
FOAMING AGENTS	0.5 mg/L		
IRON	0.3 mg/L		
MANGANESE	0.05 mg/L		
ODOR	3 THRESHOLD ODOR NUMBER		
pH	6.5-8.5		
SULFATE	250 mg/L		
TOTAL DISSOLVED SOLIDS TDS	500 mg/L		
ZINC	5 mg/L		

SECONDARY DRINKING WATER

PREPARED 6-1-82
REVISED 5-1-83

PRICE $5.00

WATER QUALITY REGULATIONS, BY TIM GANNON IN VOLUME II, WATER TREATMENT PLANT OPERATION PUBLISHED BY FOUNDATION OF CALIFORNIA STATE UNIVERSITY, SACRAMENTO, 6000 J STREET, SACRAMENTO, CALIFORNIA 95819

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